

96 00444



P.O. Box 2050
Oakland, CA 94612
(415) 464-7900

S/O

**ABAG DEPOSITORY
LIBRARY COPY**

REFERENCE ONLY

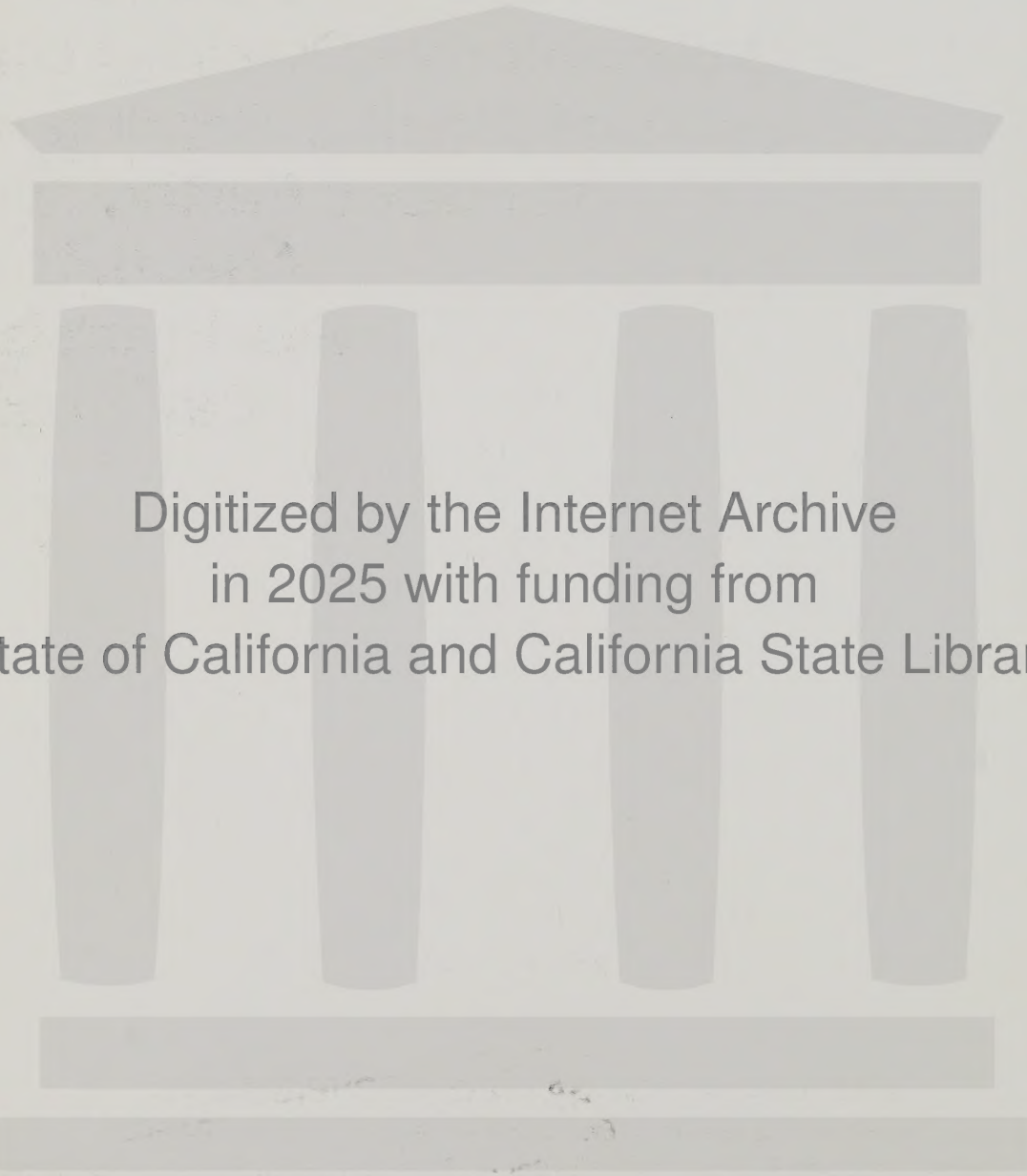
SHAKEN **AWAKE!**



**Estimates of
Uninhabitable
Dwelling Units
and Peak Shelter
Populations
in Future Earthquakes
Affecting the
San Francisco
Bay Region**

APRIL 1996

ASSOCIATION OF BAY AREA GOVERNMENTS



Digitized by the Internet Archive
in 2025 with funding from
State of California and California State Library

<https://archive.org/details/C123315495>

96 00444
104

***SHAKEN* AWAKE!**

Estimates of Uninhabitable Dwelling Units and Peak Shelter Populations in Future Earthquakes Affecting the San Francisco Bay Region

INSTITUTE OF GOVERNMENTAL
STUDIES LIBRARY

APR 29 1996

UNIVERSITY OF CALIFORNIA

APRIL 1996

ASSOCIATION OF BAY AREA GOVERNMENTS

Mailing Address: P.O. Box 2050 -- Oakland, CA 94604-2050

Location: Joseph P. Bort MetroCenter -- Eighth and Oak Streets -- Oakland

Phone: (510) 464-7900 -- Fax: (510) 464-7979

Internet Access through abagOnline at <http://www.abag.ca.gov>



Publication Number: P96002EQK

FEB 14 2025

UNIVERSITY OF CALIFORNIA

CREDITS ...**Report Authors:**

Jeanne B. Perkins -- Earthquake Program Manager, Association of Bay Area Governments
Ben Chuaqui -- Regional Planner, Association of Bay Area Governments
John Harrauld -- Director & Professor, Institute. for Disaster and Crisis Management.,
George Washington University
Dukhoon Jeong -- Research Assistant, George Washington University

Support:

Dan Friess -- Research Assistant, Association of Bay Area Governments -- building data
Fred Parkinson -- Systems Programmer, ABAG -- Loss model database programming
Hermann Schywn -- Research Assistant, George Washington University -- shelter data
Paul Wilson -- President, MapFrame Corp. -- GIS software and support
Edward Wyatt -- Environmental Engineer, Assoc. of Bay Area Governments -- building data

ABAG Management:

Eugene Y. Leong -- Executive Director
Gary Binger -- Deputy Executive Director/Planning Director

Acknowledgments:

ABAG would like to acknowledge the efforts of the following members of the Review Committee in reviewing the material which forms a basis for this document.

Earthquakes and Housing Losses Review Committee:

Thelma Rubin -- Committee Chair -- Councilmember, City of Albany
Chris Arnold -- Building Systems Development (BSD), Inc.
Roger Borchardt -- Geophysicist, U.S. Geological Survey
Laurence Kornfield -- Chief Building Inspector, City and County of San Francisco
Frank McClure -- Consulting Structural Engineer
Patrick McClellan -- former Earthquake Preparedness Coor., City of San Leandro Fire Dept.
Gregg O'Ryon -- Director, Disaster Services, American Red Cross - Bay Area
Paula Schulz -- State Hazard Mitigation Officer, California Office of Emergency Services
Roy Schweyer -- Mgr., Housing & Neigh. Preservation, Off. of Comm. Dev., Oakland
Martha Blair Tyler -- Spangle Associates, Urban Planning and Research
Frannie Winslow -- Director, Office of Emergency Services, City of San Jose

In addition, project staff wish to thank John Boatwright (USGS, Menlo Park) for his assistance in analysis of the Northridge housing data.

The writing and production of this report was financed in large part by National Science Foundation (NSF) Grants No. BCS-9302612 and CMS-9416181. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

TABLE OF CONTENTS ...

	page
Background	1
Summary	3
What We're Predicting Will Happen	9
The Peninsula San Andreas Earthquake	10
The San Gregorio Earthquake	14
The Northern Hayward Earthquake	18
The Southern Hayward Earthquake	22
The Hayward Earthquake - Entire Length	26
The Healdsburg-Rodgers Creek Earthquake	30
The Maacama Earthquake	34
The West Napa Earthquake	38
The Concord-Green Valley Earthquake	42
The Northern Calaveras Earthquake	46
The Greenville Earthquake	50
Why YOU Need to Know	55
Local Government Checklist	56
Mass Care Provider Checklist	59
How We Developed the Numbers	60
Overview	60
Intensity Mapping	62
Land Use Mapping	64
TIGER File Mapping of Census Tract and City	64
Boundaries	
Residential Building Stock	66
Matrices for Predicting Percent of Units Made	68
Uninhabitable	
Uninhabitable Units Base	70
Demographic Data Used in Peak Shelter Population	71
Modeling	
Predicting Shelter Population Based on Damage to	71
Dwellings and Demographic Data	

	page
The Issue of Accuracy -- Testing the Model by Comparing Actual Versus Predicted Values	75
Uncertainty	75
Testing the Intensity Model	75
Testing the Shelter Prediction Model	79
What Is Needed - Our Next Steps	81
City of Berkeley	82
City of San Leandro	83
City of Sunnyvale	84
City of Albany	85
City of Foster City	86
City of San Jose	87
Bibliography	88
Appendices	
Appendix A - Classification of Buildings	A-1
Appendix B - Supplementary Information on Intensity Scales and Intensity Model Accuracy	B-1
Appendix C - Data on Dwelling Units Tagged as Uninhabitable Following the Loma Prieta and Northridge Earthquakes	C-1
Appendix D - Supplemental Information on the Development of Estimates of Expected Percentages of Red- and Yellow-Tagged Units by Intensity Level Used to Model Uninhabitable Housing Units	D-1
Appendix E - The Peak Shelter Population Model	E-1
Appendix F - Predicted Uninhabitable Dwelling Units and Peak Shelter Populations by City	F-1

BACKGROUND ...

In 1992, ABAG estimated uninhabitable dwellings for future earthquakes affecting the San Francisco Bay Area with funding from the American Red Cross, the California Office of Emergency Services and ABAG itself. George Washington University (GWU) used these estimates in developing projections of shelter populations in future earthquakes in the San Francisco Bay Area.

The research which forms the basis for this document represents a significant refinement and expansion of previous efforts by ABAG and GWU. It incorporates more sophisticated ground shaking intensity models. In fact, those models were tested and refined using the loss estimation models developed for this project. It incorporates better data on the residential housing stock, including where it is located.

The Loma Prieta earthquake provided us with extremely valuable information. The residential structures tagged by local government building officials as unsafe (red) or limited access (yellow) following that earthquake have been carefully examined and analyzed. The data on daily occupancy load of Red Cross shelters were also examined.

Finally, we have been able to incorporate significant information from the Northridge earthquake in the Los Angeles area. GWU visited the Northridge area in early February 1994 to interview over 200 people in shelters or in line seeking other forms of housing assistance. GWU gathered valuable first-hand information on the demographic characteristics of those victims, as well as on the tagging of the housing which the victims had left, that is being incorporated into the Bay Area shelter model. ABAG project staff visited that area as well, traveling with a building inspector and on their own around the affected area to see first hand the damaged housing and the residential tagging process. ABAG also collected information on residential tagging from the local governments impacted in Northridge and spent days checking and refining the data provided. The ratios between green-, yellow-, and red-tagged housing units for different types of housing construction obtained from that southern California data were incorporated into the Bay Area model.

The research that formed a basis for this report had *five principal objectives*:

- 1) develop models of housing habitability based on intensity, distance from fault source, and underlying geologic materials for the San Francisco Bay Area;
- 2) model how shelter populations are related to structural damage, including data on buildings that are red-tagged as uninhabitable, as well as yellow-tagged as damaged based on actual Loma Prieta data;
- 3) assess the demographic characteristics of the shelter population versus the overall impacted population through use of the 1990 Census (conducted only five months after the earthquake) and Red Cross data from the Loma Prieta event;
- 4) relate the recovery time of the impacted housing stock to the structural type of those buildings for Loma Prieta; and
- 5) apply these lessons to future Bay Area earthquakes.

The *goal of the project* is to improve mitigation, disaster response and residential rebuilding efforts in future earthquakes. *The project should help people plan for and rebuild faster after earthquakes.*

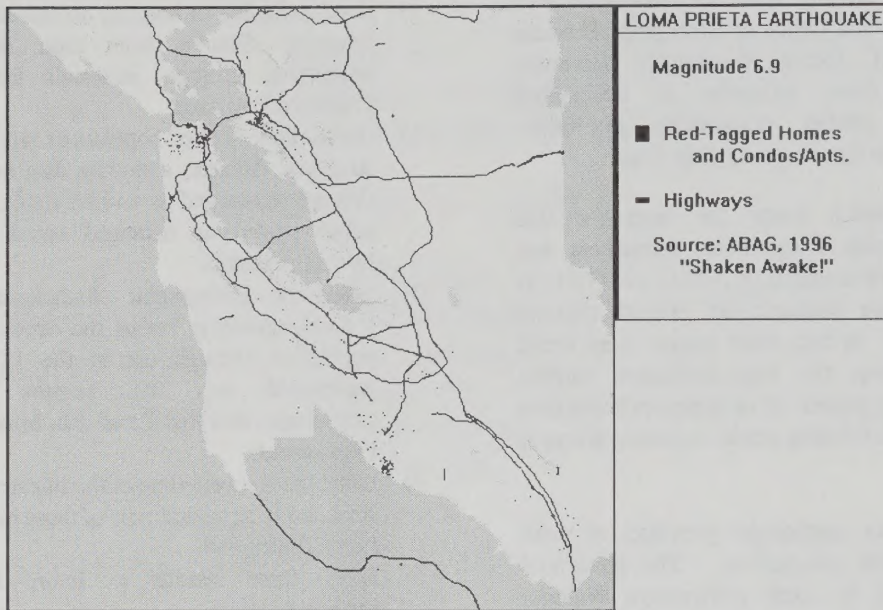
The users of this information are varied.

- 1) relief agencies, such as the American Red Cross, for use in their shelter planning efforts;
- 2) local governments for (a) conducting vulnerability analyses (which, in turn, can be used for mitigation and emergency response planning); (b) pre-planning for quicker recovery of low-income housing stock; and (c) designing more effective programs to encourage owners to retrofit housing stock.

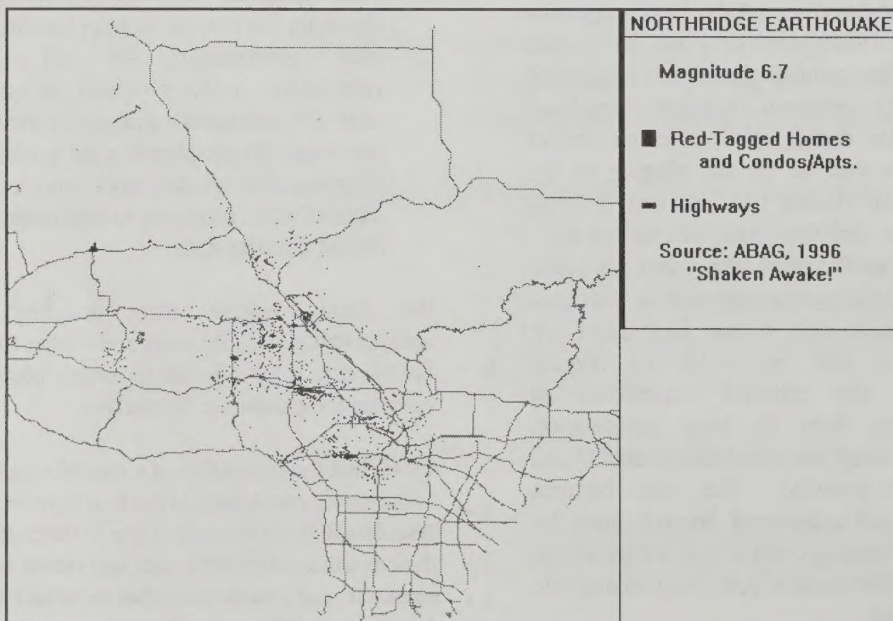
We firmly believe that modeling expected uninhabitable dwelling units and shelter needs using limited data is far superior to having potential users estimate these numbers themselves.

Given that the probability of a second major or catastrophic earthquake in the San Francisco Bay Area in the next *ten* years is one in three, the rapid dissemination of existing data and research is essential. *Let's make sure that we aren't surprised by the next earthquake disaster.*

Loma Prieta Earthquake Strikes and Results in 13,000 Uninhabitable Bay Area Housing Units



Northridge Earthquake Strikes and Results in 48,000 Uninhabitable Southern California Housing Units



SUMMARY...

We have a problem with housing people after earthquakes.

There are at least six earthquakes that will probably have more of an impact on the Bay Area's housing than Loma Prieta, and three that will be more devastating than Northridge.

The key to estimating the extent of that problem is modeling "uninhabitable" units.

The statistics are numbing. The northern Hayward fault, extending from San Pablo Bay to San Leandro, suddenly ruptures, generating a magnitude 7.1 earthquake.

- Almost 88,000 housing units are made uninhabitable.
- Over 211,000 people are forced from their homes.
- Over 63,000 people require publically provided shelter.

In another earthquake, the peninsula segment of the San Andreas fault, located in San Mateo County, ruptures, generating a magnitude 7.1 earthquake. Fewer homes and apartments are located nearby.

- "Only" 46,000 housing units are made uninhabitable.
- Almost 109,000 people are forced from their homes.
- Almost 29,000 people require publically provided shelter.

Yet each of these earthquakes are reasonably likely. The northern Hayward earthquake and the peninsula San Andreas earthquake each has about a one-in-four chance of occurring in the next 30 years.

ABAG examined the effect of eleven earthquakes on housing and shelter demand. *Six* of those earthquakes are expected to have more of an impact than the Loma Prieta earthquake in 1989 which caused a total of over 16,000 units to be uninhabitable throughout the Monterey and San Francisco Bay areas (including almost 13,000 in the Bay Area). In fact, *three* of those earthquakes will probably have a greater impact than the more recent 1994 Northridge earthquake in the Los Angeles area, in which over 48,000 housing units were made uninhabitable in the affected area.

These past earthquakes emphasize the importance of creating housing loss estimates useful for emergency response planning in the San Francisco Bay Area.

These housing loss estimates were produced using models designed to provide estimates of the number of uninhabitable dwelling units.

Uninhabitable is defined as unable to be occupied due to structural problems. It is equivalent of the Applied Technology Council (ATC) "red" tagging for unsafe buildings where entry is prohibited for single family homes. For multi-family units, the structure can be either "red" tagged or "yellow" tagged where entry is restricted. (See ATC-20, 1991.) Building departments in California uniformly use the ATC definitions in their post-earthquake tagging. Uninhabitable dwellings are not necessarily destroyed; in fact, most are repairable.

We used a five-step process to estimate uninhabitable units.

ABAG's shaking hazard maps were crucial to this modeling effort.

The relationships among habitability, construction type and intensity are based on data from past earthquakes.

The approach used in developing these estimates of uninhabitable dwelling units uses a five-step process:

- 1) estimating intensity for each of eleven future earthquakes;
- 2) developing an inventory of dwelling units by construction type (based on construction material, age, number of stories, and single vs. multi-family);
- 3) estimating dwellings in each intensity category by assigning the residential units to residential land in each intensity category;
- 4) relating intensity directly to habitability using a matrix for red and yellow tagging percentages for each combination of intensity and construction type; and
- 5) aggregating estimates of uninhabitable dwellings to obtain census tract, city (or community), county and regional totals.

The intensity maps are based on the most recent version of ABAG's ground shaking models, described in *On Shaky Ground* (Perkins and Boatwright, 1995). The scenarios examined include:

- entire Hayward fault (both northern and southern segments);
- southern segment of the Hayward fault;
- northern segment of the Hayward fault;
- Healdsburg-Rodgers Creek fault;
- Maacama fault;
- peninsula segment of the San Andreas fault;
- San Gregorio fault;
- northern Calaveras fault;
- Concord-Green Valley fault;
- Greenville fault; and
- West Napa fault.

The estimate of the percentage of each combination of intensity and construction type that is expected to be uninhabitable is based on actual statistics on residential damage in the Loma Prieta and Northridge earthquakes collected by ABAG, as well as additional data from prior earthquakes from earlier researchers (Dunne and Sonnenfeld, 1991).

The results of this modeling effort, by county, are shown in the following table. The results of the models for the Loma Prieta earthquake, as well as the actual data from that earthquake, are provided for comparison.

Uninhabitable Units for Bay Area Counties and Selected Earthquake Scenarios

County Data for Earthquake Scenarios	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Loma Prieta - Actual	3284	0	2	0	9202	76	408	0	0	12,972
Loma Prieta - Modeled	1968	159	297	1	11781	223	1239	2	3	15,673
Hayward Combined	82563	9623	2128	34	38739	1638	13443	1028	892	150,087
Southern Hayward	52200	1070	1040	7	11630	241	9963	127	30	76,309
Northern Hayward	61901	7552	2007	22	15264	237	360	333	156	87,831
Healdsburg Rodgers Creek	3256	618	1222	46	11101	71	70	139	13669	30,192
Maacama	325	17	27	22	1986	11	11	15	798	3,212
Peninsula Segment of San Andreas	3139	46	800	2	19233	13166	9336	10	4	45,735
San Gregorio	1976	28	808	2	11650	1317	324	10	6	16,119
Northern Calaveras	6231	4114	27	15	2354	58	2490	134	5	15,428
Concord-Green Valley	3546	12195	28	1173	3191	74	324	2865	35	23,431
Greenville	2413	1734	27	14	576	16	120	324	5	5,230
West Napa	1382	284	27	4129	2011	15	29	1650	126	9,652

Loss information by construction type can be used in assessing the impacts of retrofit programs.

Another way of expressing the model results is in terms of construction type, rather than by county area. These numbers estimate ways in which building retrofits can be targeted to reduce the number of uninhabitable dwelling units predicted. The results of this analysis are shown in the following table. Again, the results of the models for the Loma Prieta earthquake, as well as actual data from that earthquake, are provided for comparison.

Uninhabitable Units by Residential Construction Type for Selected Earthquake Scenarios

Construction Type Data for Earthquake Scenarios	Mobile Homes	Unreinforced Masonry	Non-Wood 4-7 Stories <1940	Non-Wood 4-7 Stories >1939	Non-Wood 7+ Stories <1940	Non-Wood 7+ Stories >1939	Wood 4-7 Stories <1940	Wood 4-7 Stories >1939	Wood 1-3 Stories <1940 Multi-Family	Wood 1-3 Stories >1939 Multi-Family	Wood 1-3 Stories <1940 Single Family	Wood 1-3 Stories >1939 Single Family
Loma Prieta - Actual	101	1936	1981	0	1230	664	3783	667	2018	216	301	75
Loma Prieta - Modeled	232	2159	1778	158	1491	1822	2819	1108	2278	1583	161	84
Hayward Combined	10892	13135	3053	1810	2580	8194	9419	9569	34234	49782	5273	2147
Southern Hayward	7793	3852	2009	368	1633	3783	3096	4962	12920	32405	2070	1417
Northern Hayward	3615	7187	2171	707	1740	4741	3838	7398	26274	24735	4443	983
Healdsburg Rodgers Creek	6697	2204	1739	216	1462	1994	2672	1172	3232	7937	465	404
Maacama	475	703	311	0	262	103	630	83	301	245	74	27
Peninsula Segment of San Andreas	1659	2490	1901	1549	1494	3220	5283	4905	6303	15909	605	416
San Gregorio	328	2107	1791	152	1465	1658	2817	1270	2230	2061	168	75
Northern Calaveras	1688	1159	608	12	454	445	743	1228	1108	7296	166	521
Concord-Green Valley	3660	1220	735	9	448	709	1157	1590	1952	11060	322	569
Greenville	974	351	330	0	191	105	426	207	571	1871	98	107
West Napa	2315	929	604	0	403	206	683	180	1313	2577	256	188

Our biggest problems occur when all or part of the Hayward fault ruptures.

Note that these loss estimates are limited to SHAKING damage.

Local government options for using these data include:

In both these tables, it is important to note the huge number of predicted uninhabitable dwellings in the entire Hayward, northern Hayward, and southern Hayward scenarios relative to the other eight scenarios.

The emphasis of this effort is on determining damage due to ground shaking, not on potential additional lost housing due to fire following an earthquake, liquefaction, and earthquake-induced landsliding. However, estimates of such additional uninhabitable units could be made in the future based on available models, together with ways to improve those estimates with additional research.

Local governments have a number of different options for using these results, as well as the more detailed information given later in this report and in the Appendices.

***Building department -
emergency inspection
impacts***

1) Data on the number of dwelling units predicted to be red- or yellow-tagged can alert building departments on the relative man-power needs for post-earthquake safety evaluations associated with various scenario earthquakes. The absolute man-power requirements are obviously related to other factors, such as the extent of minor damage which causes housing renters or owners to request inspections, which are not addressed in this document.

***Housing department -
low-income housing
impacts***

2) Housing and community development departments may be interested in the type of buildings being red- or yellow-tagged. For example, those living in some types of buildings (such as mobile homes and unreinforced masonry single-room occupancy apartments) tend to have demographic characteristics of significance in emergency shelter planning, as well as in estimating long-term housing assistance requirements.

***Public relations -
neighborhood outreach
for preparedness***

3) Community education campaigns intended to reinforce the message to neighborhood groups of the need to retrofit and seismically strengthen pre-1940 wood-frame dwellings located in areas that have greater exposure to high intensity ground shaking.

***Predicting peak shelter
populations are the next
step.***

Agencies responsible for providing short-term emergency shelter can use these estimates to predict mass care requirements. To provide information useful for these organizations, George Washington University (GWU) has been working with ABAG to develop models that combine the tagging data with demographic information essential for these forecasts.

***1 - Calculate households
seeking alternative
shelters***

All of those households living in uninhabitable dwellings (red-tagged or multi-family yellow-tagged) will be seeking alternative shelter. Many will stay with friends and relatives or in the family car. Some will stay in public shelters provided by the Red Cross or others. Those seeking public shelter can be estimated from past disasters, including both hurricanes and earthquakes. Those seeking shelter typically have very low incomes for these families have fewer options. Other variables, such as ethnicity and housing ownership, have a modifying effect on the results.

***2 - Calculate how many
of those will seek public
shelter (due largely to low
incomes)***

The results of this modeling process are shown in the following table.

Peak Shelter Population for Bay Area Counties and Selected Earthquake Scenarios

County Data for Earthquake Scenarios	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Loma Prieta - Actual	772	0	0	0	1650	679	164	0	0	3,265
Loma Prieta - Modeled	1409	116	189	0	7865	130	807	1	0	10,517
Hayward Combined	60001	6989	1317	22	26198	1152	9145	793	595	106,212
Southern Hayward	38228	762	632	4	7765	151	7030	96	18	54,686
Northern Hayward	45493	5784	1239	15	10233	147	235	254	96	63,496
Healdsburg Rodgers Creek	2217	457	744	29	7411	45	42	103	9028	20,076
Maacama	235	7	13	14	1319	4	6	10	544	2,152
Peninsula Segment of San Andreas	2139	31	489	1	12905	7966	5447	6	0	28,984
San Gregorio	1392	18	493	1	7777	806	177	6	1	10,671
Northern Calaveras	4095	2261	14	9	1565	39	1866	102	0	9,951
Concord-Green Valley	2415	7342	14	768	2123	48	216	2172	22	15,120
Greenville	1654	1145	14	9	390	6	83	262	1	3,564
West Napa	1030	191	14	2736	1336	6	17	1284	72	6,686

Note: some factors are not addressed by the modeling.

This report replaces the 1992 work by ABAG and GWU on residential impacts of earthquakes on mass care.

Note that this modeling process does not include three important influences on shelter populations:

- pre-disaster homeless;
- secondary disasters (such as toxic gas releases and fires); and
- non-resident populations (such as tourists and commuters).

The research that forms the basis for these loss estimates and mass care requirements is significantly more sophisticated than that used in earlier estimates by ABAG and GWU produced for the California Office of Emergency Services (OES) and the American Red Cross in 1992 (Perkins, 1992; Harrald and others, 1992). Therefore, those earlier documents should be considered superseded by this report.

WHAT WE'RE PREDICTING WILL HAPPEN ...

The following pages summarize the results of the models for each scenario. The earthquake summaries provide

- estimates of uninhabitable dwelling units by construction type and county; and
- estimates of the minimum number of people required to seek public shelter.

ABAG recommends that this entire report be read before using the numbers for emergency or mitigation planning.

Note that this modeling process does not include three important influences on shelter populations:

- pre-disaster homeless;
- secondary disasters (such as toxic gas releases and fires); and
- non-resident populations (such as tourists and commuters).

The values are aggregated from modeling performed on individual census tracts. Total values are more accurate than values for specific counties and building types.

Some users may wish the results aggregated by city, rather than by county. Those users should refer to Appendix F.

San Andreas Earthquake -- Peninsula Segment -- Impacts

This scenario earthquake is for a magnitude 7.1 earthquake on the Peninsula segment of the San Andreas fault.

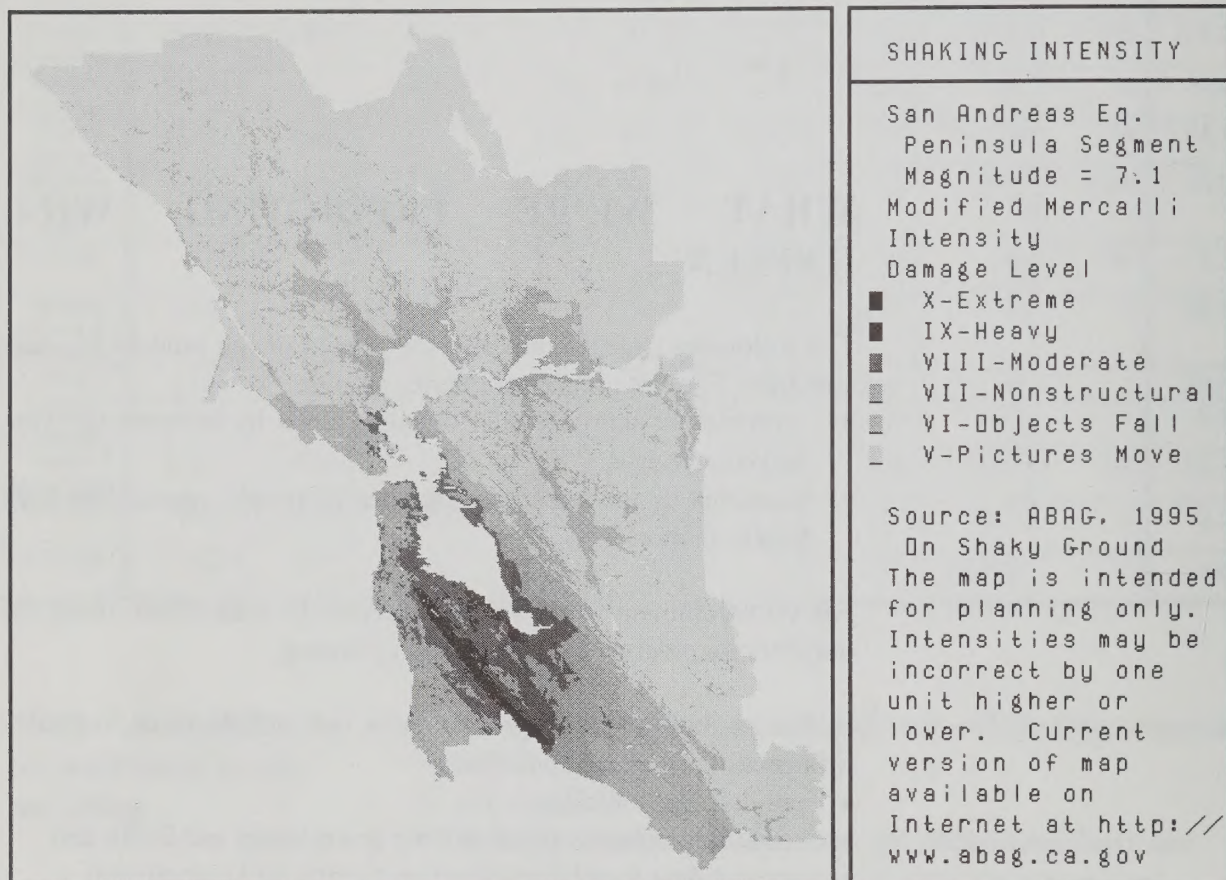


TABLE -- ESTIMATE OF UNINHABITABLE DWELLING UNITS

Construction Type	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Mobile Homes	137	0	22	0	8	706	786	0	0	1659
Unreinforced Masonry	345	7	4	0	2004	100	29	2	1	2490
Non-Wood, 4-7 Stories, <1940	292	0	0	0	1456	41	109	3	0	1901
Non-Wood, 4-7 Stories, >1939	9	0	0	0	729	528	283	0	0	1549
Non-Wood, 8+ Stories, <1940	183	0	0	0	1282	0	29	0	0	1494
Non-Wood, 8+ Stories, >1939	276	0	0	0	1906	703	334	0	0	3220
Wood-Frame, 4-7 Stories, <1940, Multi-Family	60	0	1	0	5117	105	1	0	0	5283
Wood-Frame, 4-7 Stories, >1939, Multi-Family	539	8	97	0	867	2497	897	0	0	4905
Wood-Frame, 1-3 Stories, <1940, Multi-Family	471	14	64	1	4002	1213	535	3	1	6303
Wood-Frame, 1-3 Stories, >1939, Multi-Family	759	14	588	1	1685	6805	6055	2	2	15909
Wood-Frame, 1-3 Stories, <1940, Single Family	48	3	17	0	161	260	114	1	1	605
Wood-Frame, 1-3 Stories, >1939, Single Family	19	1	7	0	18	207	165	0	0	416
"Other" (tents, caves, boats, etc.)	0	0	0	0	0	0	0	0	0	0
TOTAL	3139	46	800	2	19233	13166	9336	10	4	45735

An earthquake along the Peninsula segment of the San Andreas fault would cause a predicted housing loss of over 45,000 dwelling units. Of these uninhabitable units, 42% are predicted to be within San Francisco. Most of the rest of the total forecasted uninhabitable dwelling units are predicted to be in San Mateo (29%), Santa Clara (20%) and Alameda (7%) counties.

It is important to note that these numbers are higher in San Francisco than in the County of San Mateo, which is geographically closer to the fault line. Damage in San Francisco County is higher than that in San Mateo County by 46% (in calculating the percentages by which one county *exceeds* another, the higher number is divided by the smaller and 100% is deducted). In San Francisco, almost 6% of the total housing stock is made uninhabitable versus just over 5% in San Mateo County (see page 67 for existing total dwelling units by county). San Francisco's denser, older and more vulnerable housing types play a significant role in determining this damage pattern.

**FIGURE -- HOUSING IMPACTS OF AN EARTHQUAKE ON THE PENINSULA SEGMENT OF THE
SAN ANDREAS FAULT**

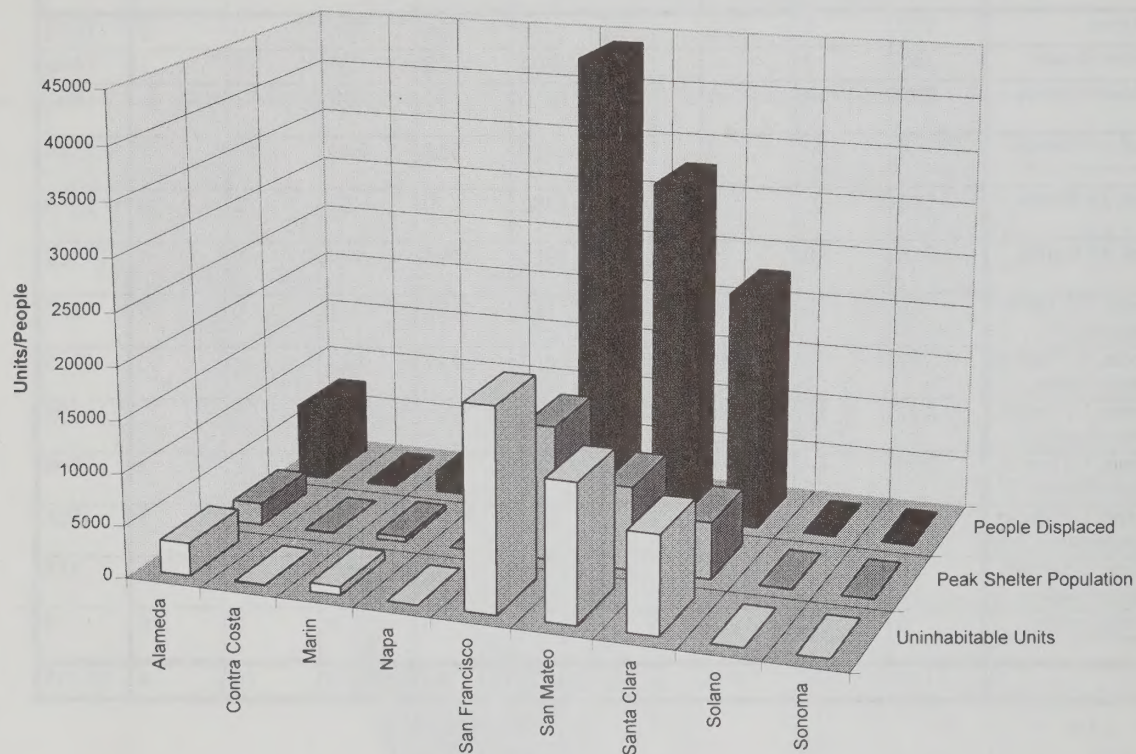


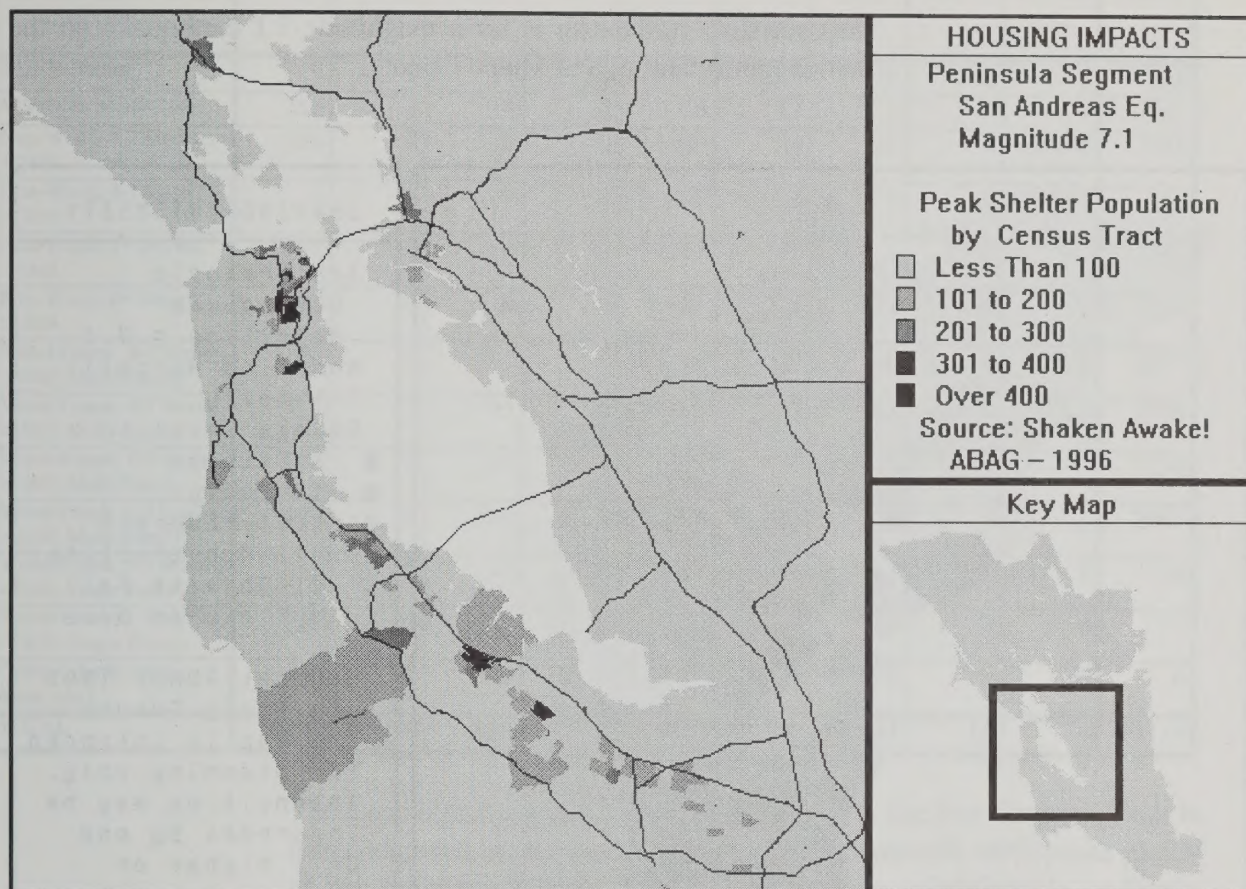
TABLE -- PEOPLE DISPLACED

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Displaced	2742	47	833	1	18041	15152	9924	5	4	46749
Yellow Tag # People Displaced	4611	72	1184	3	25974	17502	12781	24	8	62159
Total # of People Displaced	7353	119	2017	4	44015	32654	22705	29	12	108908

TABLE -- PEAK SHELTER POPULATION

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Sheltered	806	13	213	0	5425	3843	2471	1	0	12772
Yellow Tag # People Sheltered	1333	18	276	1	7480	4123	2976	5	0	16212
Total Shelter Population	2139	31	489	1	12905	7966	5447	6	0	28984

FIGURE -- PEAK SHELTER POPULATION



San Francisco County possesses the highest numbers of displaced and shelter populations. The high percentage of the total peak shelter population (45%) reflects the large percentage of uninhabitable units there (42%). However, because there are fewer number of individuals per dwelling unit in San Francisco County, its displaced population represents only 40% of the total. In addition to the impact of uninhabitable units, demographic factors such as income and household type make inner city areas have the largest shelter needs, offsetting the effects of smaller household size in these areas.

The housing impacts of this earthquake are higher in San Francisco than in San Mateo County where the fault source of this earthquake is located. This discrepancy points to the role of housing type and demographic factors, particularly household income, in predicting peak shelter population.

San Gregorio Earthquake Impacts

This scenario earthquake is for a magnitude 7.1 earthquake on the San Gregorio fault in San Mateo County.

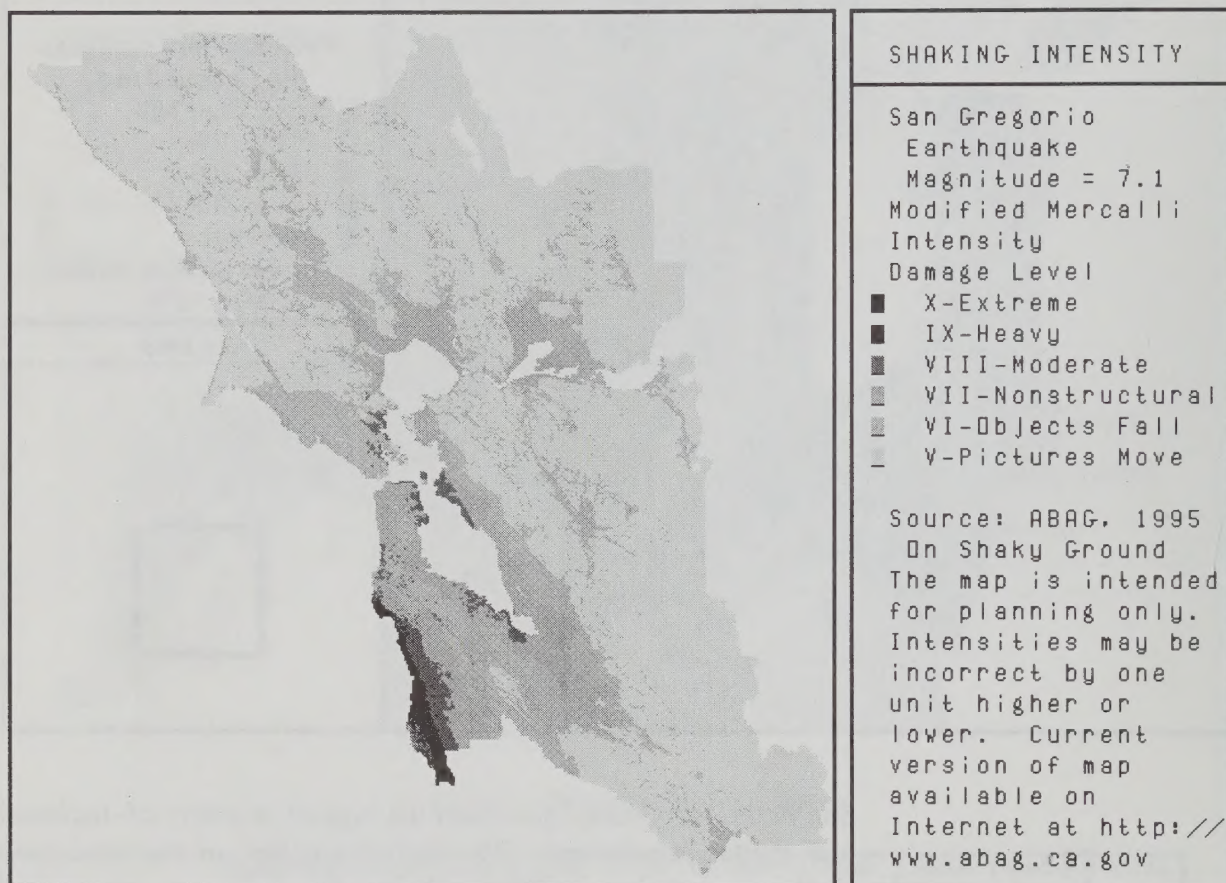


TABLE -- ESTIMATE OF UNINHABITABLE DWELLING UNITS

Construction Type	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Mobile Homes	9	0	23	0	1	263	32	0	0	328
Unreinforced Masonry	280	3	4	0	1799	13	4	2	1	2107
Non-Wood, 4-7 Stories, <1940	286	0	0	0	1406	26	70	3	0	1791
Non-Wood, 4-7 Stories, >1939	0	0	0	0	148	3	0	0	0	152
Non-Wood, 8+ Stories, <1940	177	0	0	0	1282	0	5	0	0	1465
Non-Wood, 8+ Stories, >1939	103	0	0	0	1483	51	21	0	0	1658
Wood-Frame, 4-7 Stories, <1940, Multi-Family	50	0	1	0	2746	20	0	0	0	2817
Wood-Frame, 4-7 Stories, >1939, Multi-Family	337	2	97	0	450	323	61	0	0	1270
Wood-Frame, 1-3 Stories, <1940, Multi-Family	290	11	65	1	1704	113	42	3	1	2230
Wood-Frame, 1-3 Stories, >1939, Multi-Family	403	10	594	1	554	421	74	2	3	2061
Wood-Frame, 1-3 Stories, <1940, Single Family	31	2	17	0	68	42	7	1	1	168
Wood-Frame, 1-3 Stories, >1939, Single Family	10	1	7	0	9	41	7	0	0	75
"Other" (tents, caves, boats, etc.)	0	0	0	0	0	0	0	0	0	0
TOTAL	1976	28	808	2	11650	1317	324	10	6	16119

The overall damage from an earthquake along the San Gregorio fault is less compared to that on the San Andreas Peninsula earthquake (3.5% of San Francisco County's total stock is made uninhabitable, and only 0.5% of San Mateo County's total stock is made uninhabitable). However, the damage pattern of the San Andreas fault, where San Francisco is impacted more heavily than San Mateo County, is magnified. With an earthquake along the San Gregorio fault, the impacts in San Francisco in terms of uninhabitable dwelling units are almost nine times greater than those in San Mateo County. This damage pattern is due to building stock differences in age and density between the two counties, even though the earthquake source is in San Mateo County.

An analogous effect is taking place in Alameda County. Although Alameda County is significantly farther away from the source of the event than San Mateo County, Alameda County's housing stock tends to be both older and more susceptible to earthquake damage. This is apparent from looking at the damage estimates for the pre- 1940 categories which tend to be higher in both San Francisco and Alameda counties.

FIGURE --HOUSING IMPACTS OF AN EARTHQUAKE ON THE SAN GREGORIO FAULT

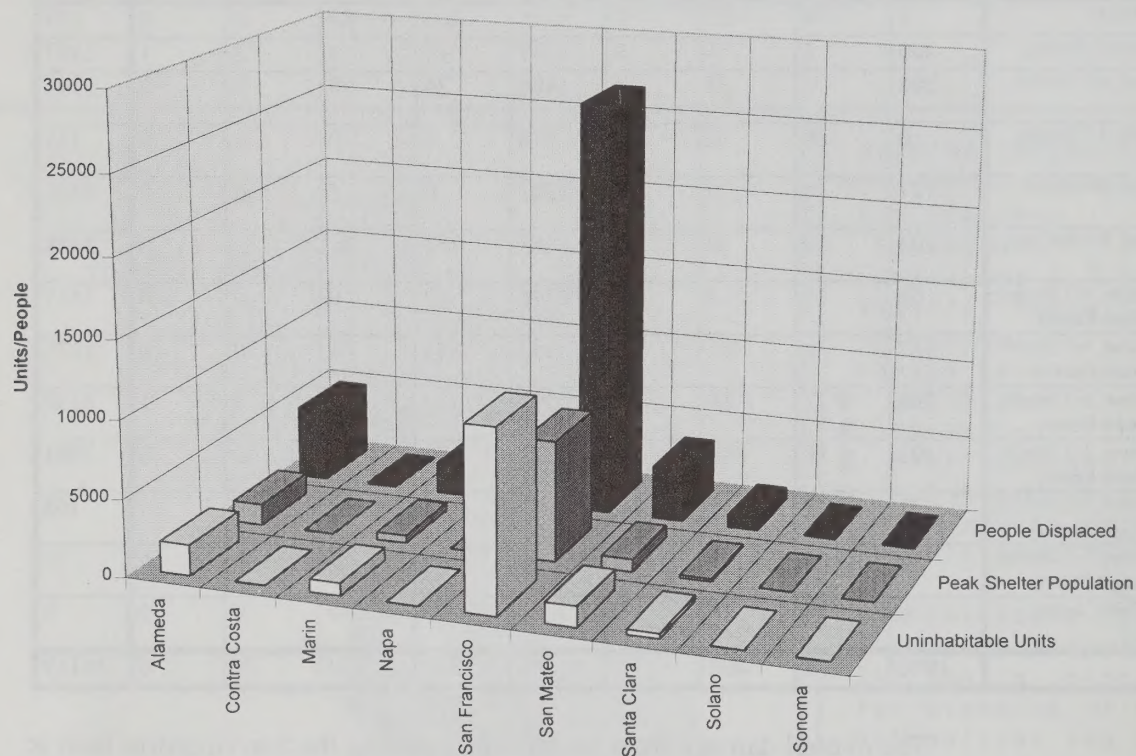


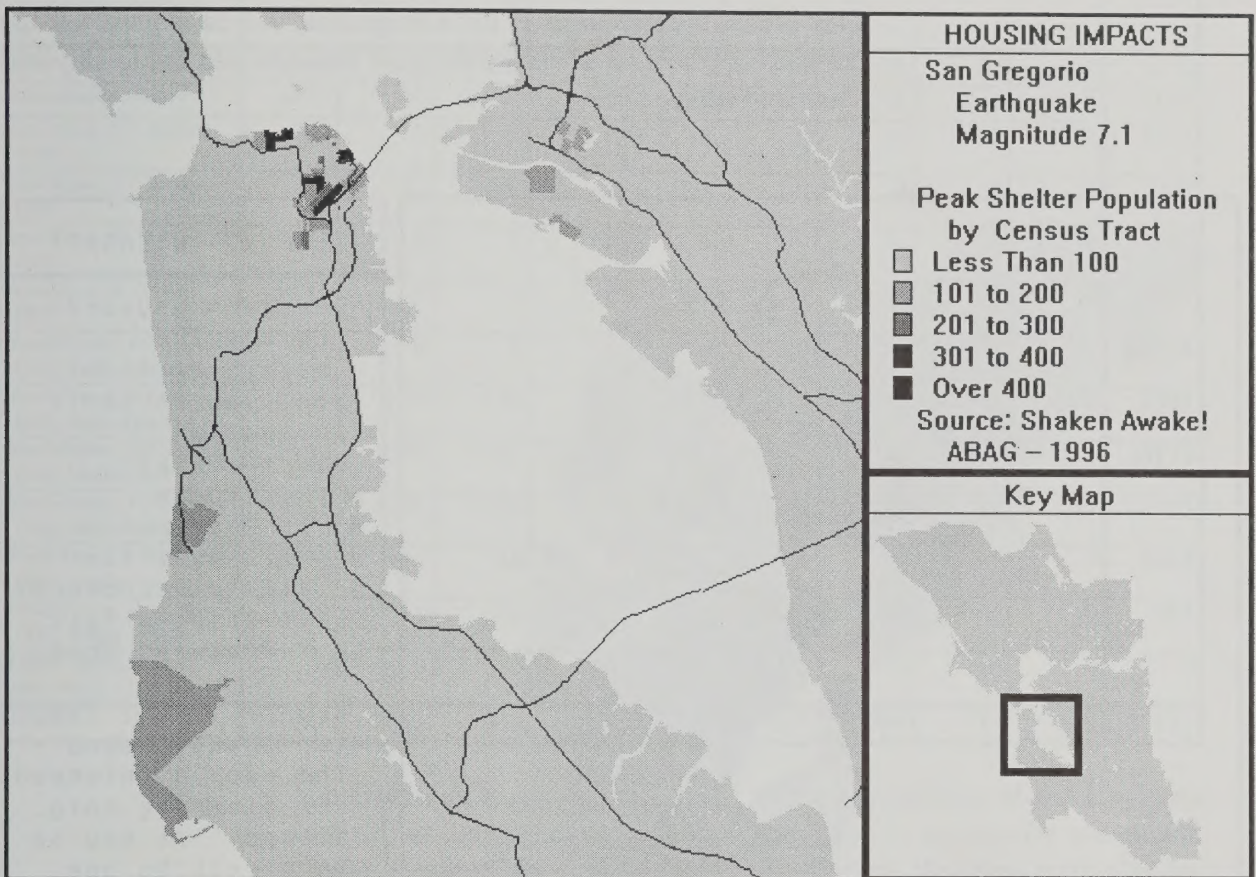
TABLE -- PEOPLE DISPLACED

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Displaced	1335	21	843	2	7768	1600	235	5	5	11816
Yellow Tag # People Displaced	3429	52	1195	3	18892	1879	544	24	9	26027
Total # of People Displaced	4765	73	2038	4	26660	3479	779	29	15	37843

TABLE -- PEAK SHELTER POPULATION

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Sheltered	392	5	215	0	2336	373	56	1	0	3378
Yellow Tag # People Sheltered	1000	13	278	1	5441	433	121	5	1	7293
Total Shelter Population	1392	18	493	1	7777	806	177	6	1	10671

FIGURE -- PEAK SHELTER POPULATION



Following the pattern of uninhabitable dwelling units, the peak shelter population estimate for San Francisco is almost ten times higher than in San Mateo County, where the earthquake source is located.

The difference between older and denser urban counties and newer and more suburban ones is evident when comparing the uninhabitable dwelling units of Alameda and San Mateo counties with their respective shelter populations. While there are 50% more uninhabitable dwelling units in Alameda County than in San Mateo County, there are only 37% more people displaced due to fewer average people per household. This "reduction" is more than offset by the demographic factors, particularly income, which result in over 72% more people requiring shelter in Alameda County than in San Mateo County. At the same time, 72% of the shelter-seeking population in Alameda County is generated by yellow-tagged dwelling units while in San Mateo County this number drops to 54%. These differences result from statistics showing that individuals within older and denser urban counties are more likely to go to shelters than those living in newer more suburban counties.

Northern Hayward Earthquake Impacts

This scenario earthquake is for a magnitude 7.1 earthquake on the northern segment of the Hayward fault between San Pablo Bay and southern Oakland.

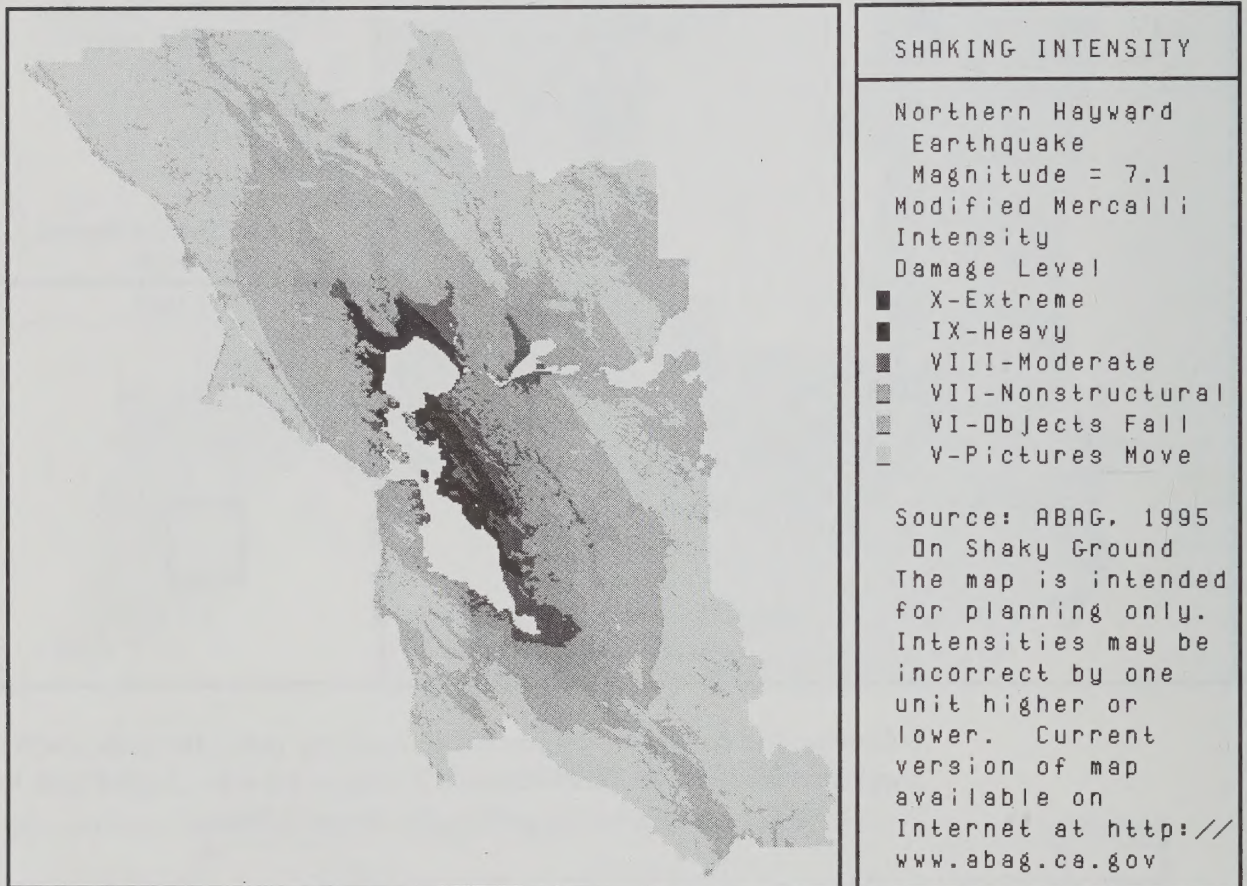


TABLE -- ESTIMATE OF UNINHABITABLE DWELLING UNITS

Construction Type	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Mobile Homes	1935	970	459	8	2	10	72	82	77	3615
Unreinforced Masonry	3973	47	8	0	3137	11	3	5	3	7187
Non-Wood, 4-7 Stories, <1940	705	0	0	0	1427	6	13	21	0	2171
Non-Wood, 4-7 Stories, >1939	393	83	0	0	231	0	0	0	0	707
Non-Wood, 8+ Stories, <1940	421	0	0	0	1296	0	23	0	0	1740
Non-Wood, 8+ Stories, >1939	2816	1	1	0	1888	17	18	1	0	4741
Wood-Frame, 4-7 Stories, <1940, Multi-Family	602	0	2	0	3229	5	1	0	0	3838
Wood-Frame, 4-7 Stories, >1939, Multi-Family	6314	150	190	0	602	106	36	0	0	7398
Wood-Frame, 1-3 Stories, <1940, Multi-Family	22629	1000	102	7	2368	37	75	45	11	26274
Wood-Frame, 1-3 Stories, >1939, Multi-Family	17657	4559	1166	4	1004	35	95	169	47	24735
Wood-Frame, 1-3 Stories, <1940, Single Family	3890	411	38	2	71	6	11	6	7	4443
Wood-Frame, 1-3 Stories, >1939, Single Family	568	331	42	1	8	5	14	4	10	983
"Other" (tents, caves, boats, etc.)	0	0	0	0	0	0	0	0	0	0
TOTAL	61901	7552	2007	22	15264	237	360	333	156	87831

The effects of a strong earthquake along any portion of the Hayward fault would be devastating because this area is so heavily urbanized. Of the damage forecasts outlined in this report, the three estimates for events along the Hayward fault (northern segment, southern segment and the entire length) are clearly the most devastating. The predicted damage for an event along the northern segment of the Hayward fault is next in damage only to an event along the entire length of this fault. Almost 88,000 dwelling units are predicted to become uninhabitable and of these, 88% are forecasted to be in either Alameda or San Francisco counties.

In all three scenarios of the Hayward fault, Alameda County is consistently the hardest hit. During an event on the northern segment of the Hayward fault, the estimates of uninhabitable dwellings in Alameda County are higher by a factor of four and eight than in the next hardest hit counties -- San Francisco and Contra Costa counties respectively. An estimated 90% of Alameda County's unreinforced masonry (URM) building stock would be deemed uninhabitable. In terms of actual numbers, the highest damage is estimated to occur to one to three story multi-family construction; an estimated 47% of these units built prior to 1940 and 15% of the units built after 1940 would be deemed uninhabitable in Alameda County.

FIGURE -- HOUSING IMPACTS OF AN EARTHQUAKE ON THE NORTHERN HAYWARD FAULT

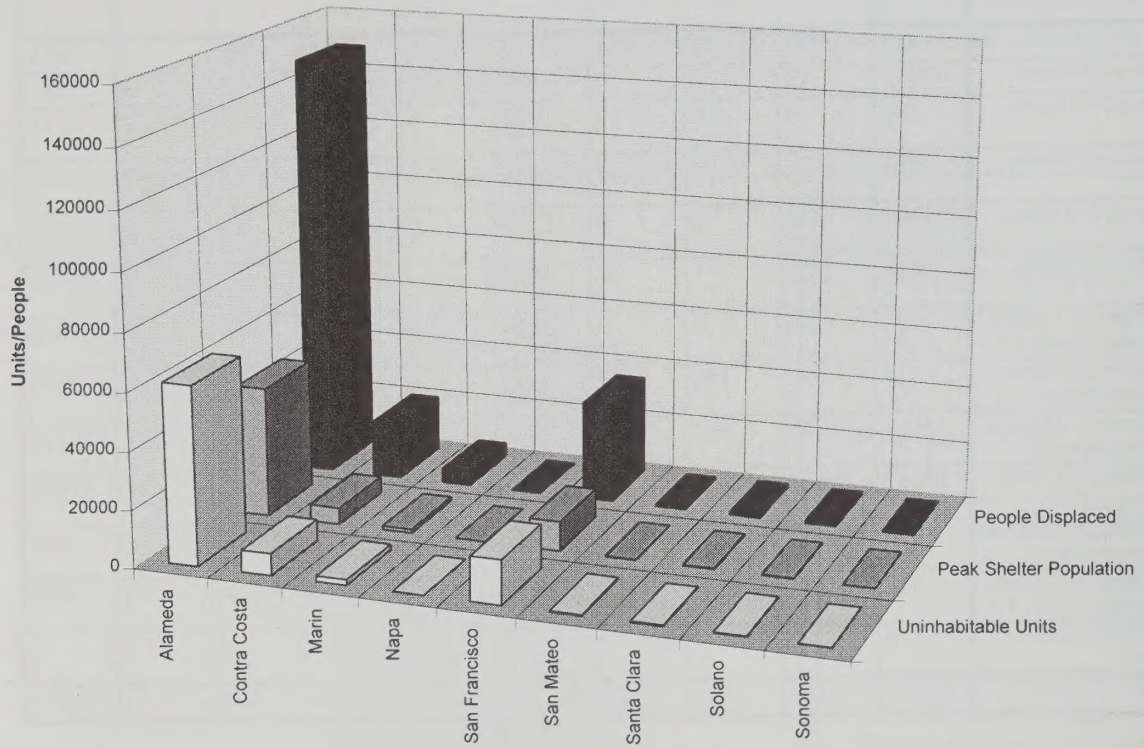


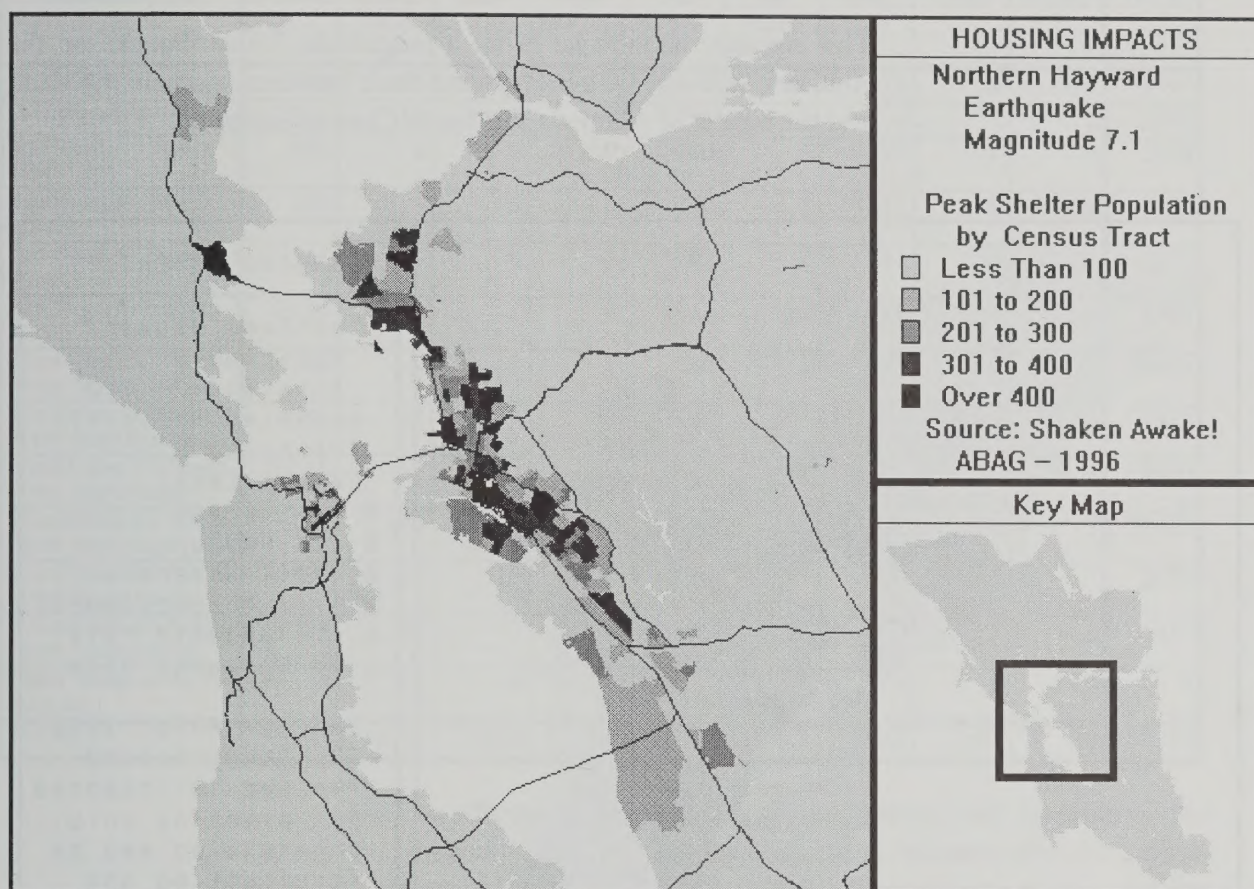
TABLE -- PEOPLE DISPLACED

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Displaced	92761	12779	3049	38	13585	137	431	505	292	123577
Yellow Tag # People Displaced	55600	7100	1933	20	21347	465	549	442	112	87568
Total # of People Displaced	148361	19879	4982	58	34932	602	980	947	404	211145

TABLE -- PEAK SHELTER POPULATION

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Sheltered	29050	3819	783	10	4085	34	108	140	74	37749
Yellow Tag # People Sheltered	16443	1965	456	5	6148	113	127	114	22	25143
Total Shelter Population	45493	5784	1239	15	10233	147	235	254	96	63496

FIGURE -- PEAK SHELTER POPULATION



As in the case of the estimate of uninhabitable dwelling units, Alameda County is again the hardest hit in terms of both displaced and peak shelter populations. Almost 150,000 people in Alameda County would be displaced, creating a need to shelter over 45,000 people in that county alone.

The peak shelter population is not limited to the area adjacent to the fault, however. In fact, the largest shelter requirements are in areas not directly adjacent to the fault but within inner city areas where the shaking intensities would not be the highest. Because shelter population calculations include income and other demographic variables, central city areas are impacted the most. Both Alameda and San Francisco counties are expected to produce the highest percentages of shelter populations relative to their respective displaced population. In each case, approximately 30% of their displaced population, about 5% higher than Marin or Santa Clara counties, is expected to go to shelters.

Southern Hayward Earthquake Impacts

This scenario earthquake is for a magnitude 7.0 earthquake on the southern segment of the Hayward fault between southern Oakland and the border of Alameda and Santa Clara counties.

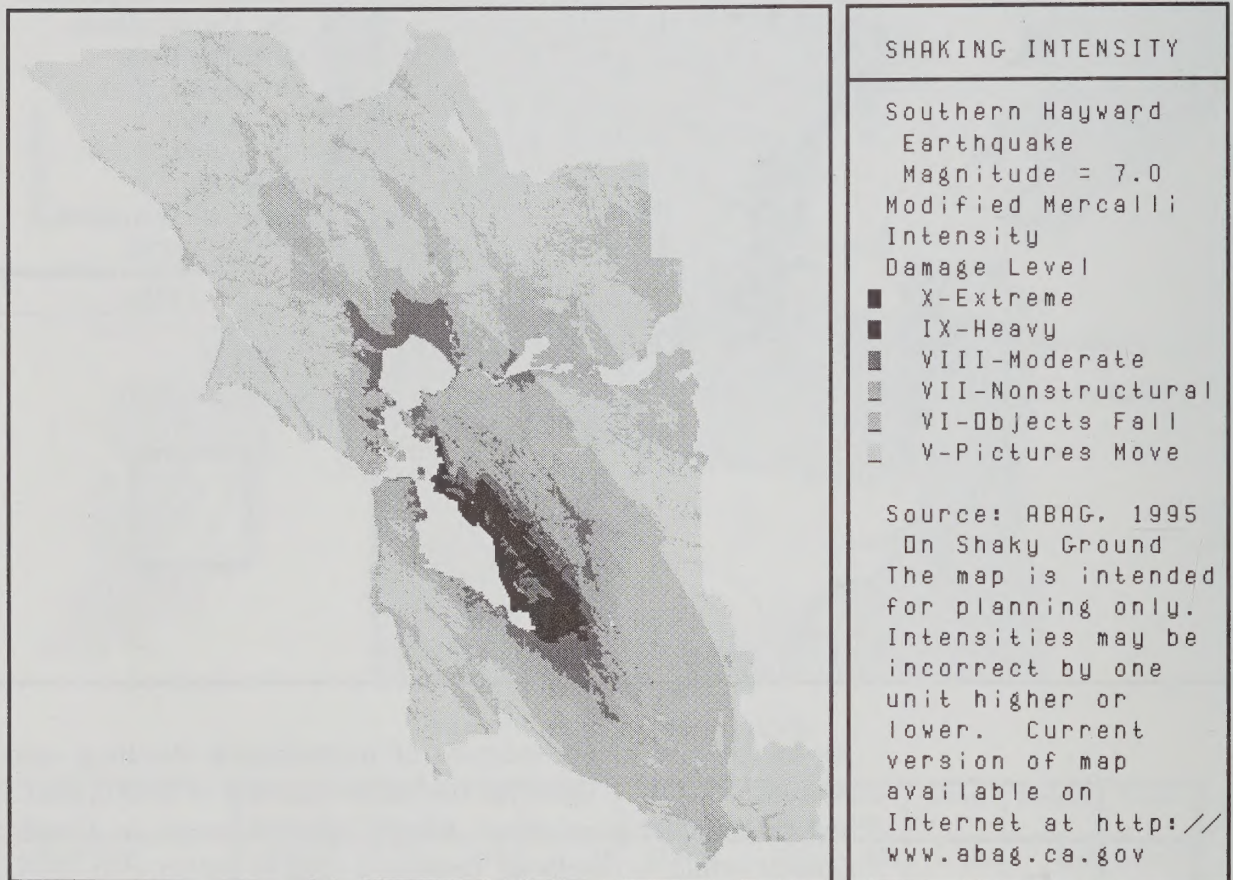


TABLE -- ESTIMATE OF UNINHABITABLE DWELLING UNITS

Construction Type	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Mobile Homes	4259	38	111	0	1	10	3353	8	14	7793
Unreinforced Masonry	2006	16	8	0	1799	11	6	5	1	3852
Non-Wood, 4-7 Stories, <1940	506	0	0	0	1406	6	70	21	0	2009
Non-Wood, 4-7 Stories, >1939	162	6	0	0	172	0	29	0	0	368
Non-Wood, 8+ Stories, <1940	311	0	0	0	1282	0	41	0	0	1633
Non-Wood, 8+ Stories, >1939	2152	1	1	0	1384	17	228	1	0	3783
Wood-Frame, 4-7 Stories, <1940, Multi-Family	346	0	2	0	2740	5	3	0	0	3096
Wood-Frame, 4-7 Stories, >1939, Multi-Family	4041	67	119	0	446	106	184	0	0	4962
Wood-Frame, 1-3 Stories, <1940, Multi-Family	10241	116	69	4	1686	38	722	39	4	12920
Wood-Frame, 1-3 Stories, >1939, Multi-Family	25118	776	702	2	649	36	5072	44	7	32405
Wood-Frame, 1-3 Stories, <1940, Single Family	1857	20	19	1	60	7	98	6	3	2070
Wood-Frame, 1-3 Stories, >1939, Single Family	1201	32	12	0	6	5	157	3	1	1417
"Other" (tents, caves, boats, etc.)	0	0	0	0	0	0	0	0	0	0
TOTAL	52200	1070	1040	7	11630	241	9963	127	30	76309

The effects of a strong earthquake along any portion of the Hayward fault would be devastating because this area is so heavily urbanized. An event along the southern segment of the fault would again be hardest felt in Alameda County. This time though, there is significantly more damage to post-1939 one to three story multi-family dwellings; during an event on the southern segment of the Hayward fault, the damage to dwellings in these types of buildings is over 40% greater than the damage to them in the event of the northern segment. The reason for this pattern is that this type of construction is more common in the southern cities of Alameda County which were more recently urbanized than the older northern cities.

Also significant with the southern segment of the Hayward fault is the fact that the damage estimate to San Francisco is greater than it is in Santa Clara County, even though, geographically, Santa Clara County is closer to the fault. As in the case of Alameda County in the event of the San Gregorio earthquake, San Francisco's housing stock includes buildings which are older and more susceptible to earthquake damage.

FIGURE -- HOUSING IMPACTS OF AN EARTHQUAKE ON THE SOUTHERN HAYWARD FAULT

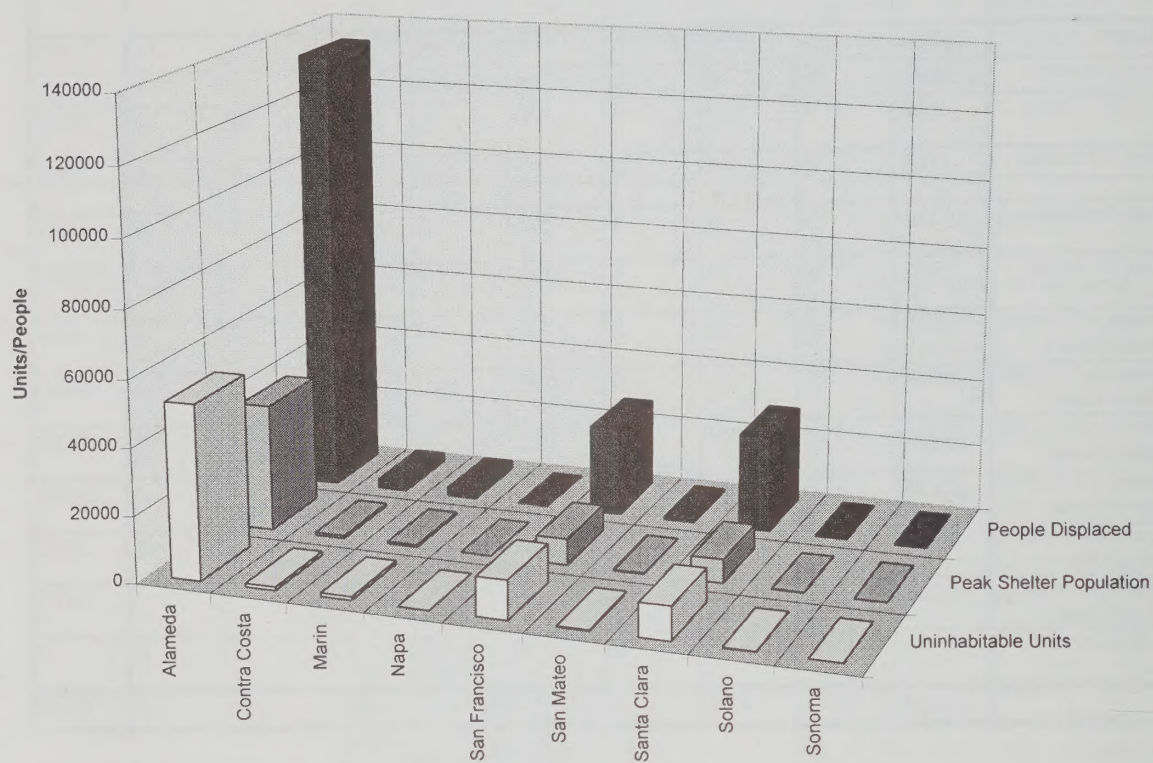


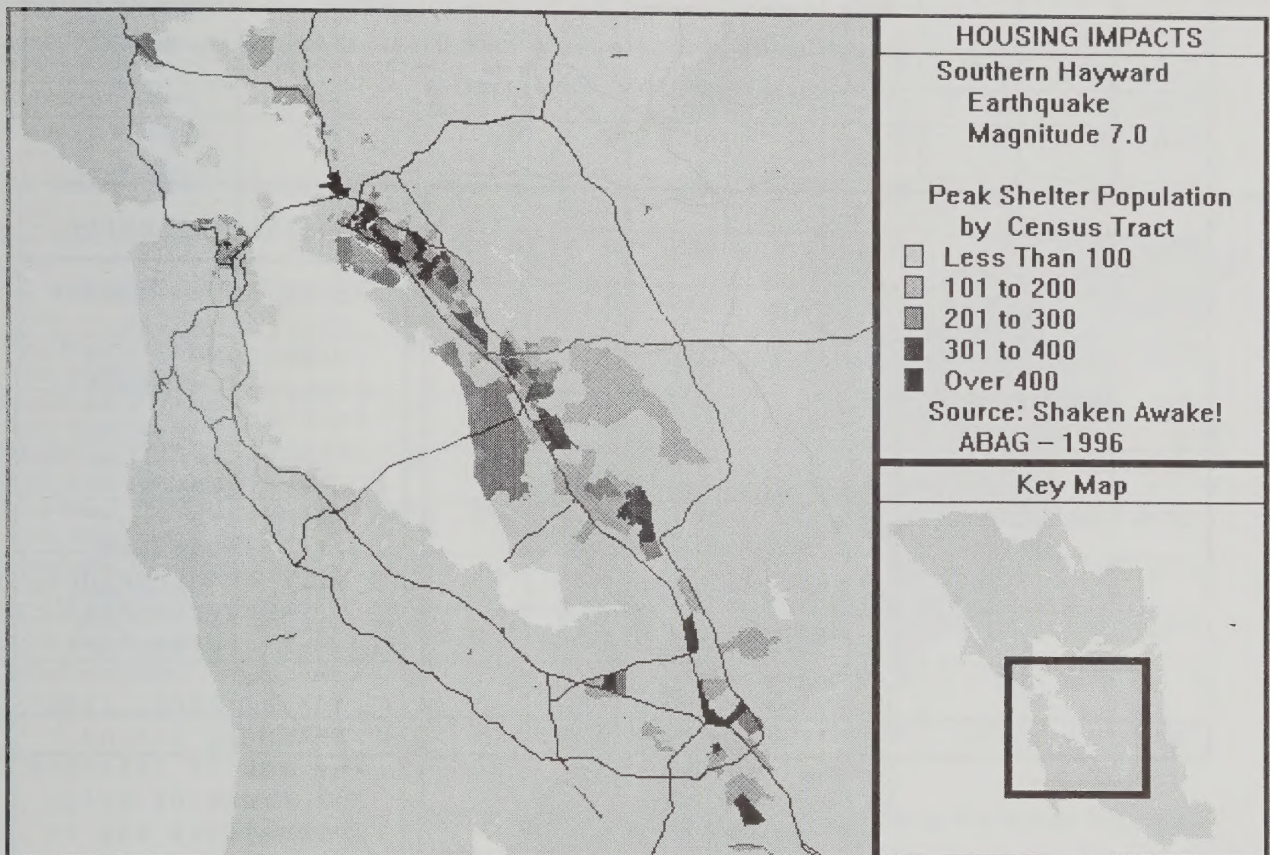
TABLE -- PEOPLE DISPLACED

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Displaced	80110	1151	1180	9	7828	140	17219	158	54	107849
Yellow Tag # People Displaced	53402	1636	1410	10	18788	470	11439	205	23	87383
Total # of People Displaced	133512	2787	2590	19	26616	610	28658	363	77	195232

TABLE -- PEAK SHELTER POPULATION

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Sheltered	23404	329	302	2	2354	36	4354	44	13	30838
Yellow Tag # People Sheltered	14824	433	330	2	5411	115	2676	52	5	23848
Total Shelter Population	38228	762	632	4	7765	151	7030	96	18	54686

FIGURE -- PEAK SHELTER POPULATION



As in the case of the estimate of uninhabitable dwelling units, Alameda County is again the hardest hit in terms of both displaced and peak shelter populations. Over 130,000 people in Alameda County would be displaced, creating a need to shelter over 38,000 people in that county alone.

San Francisco and Santa Clara counties show similar peak shelter estimates. While the peak shelter estimate is 10% higher in San Francisco than in Santa Clara County, the total displaced population is actually higher in Santa Clara by 8%. This difference can be attributed to the impact of demographic factors, such as income and household type, in the calculations of peak shelter population.

Hayward Earthquake -- Entire Length - Impacts

This scenario earthquake is for a magnitude 7.3 earthquake on the entire length of the Hayward fault from San Pablo Bay to the border of Alameda and Santa Clara counties.

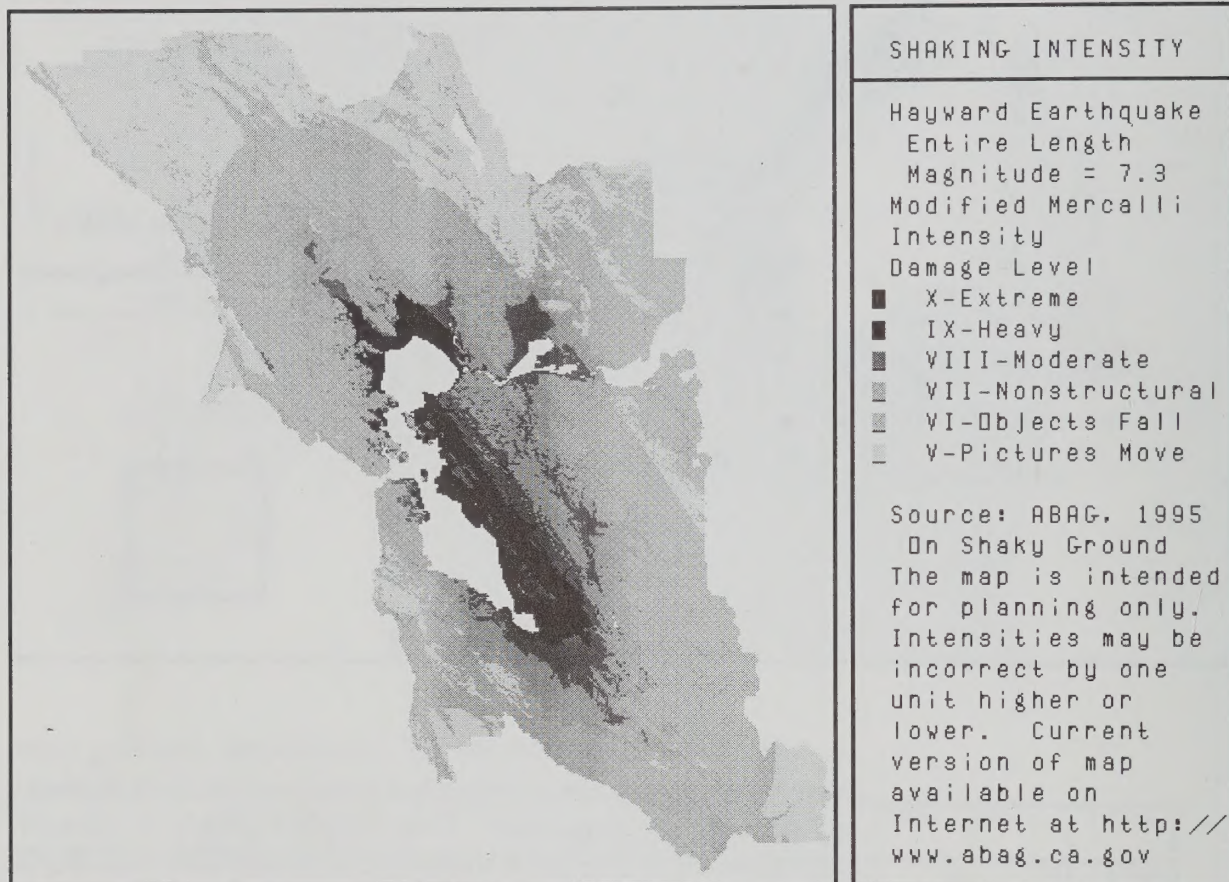


TABLE -- ESTIMATE OF UNINHABITABLE DWELLING UNITS

Construction Type	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Mobile Homes	4647	1418	467	14	15	99	3639	262	331	10892
Unreinforced Masonry	4040	51	8	0	8960	37	9	28	3	13135
Non-Wood, 4-7 Stories, <1940	708	0	0	0	2186	22	70	68	0	3053
Non-Wood, 4-7 Stories, >1939	398	83	0	0	1067	233	29	0	0	1810
Non-Wood, 8+ Stories, <1940	421	0	0	0	2118	0	41	0	0	2580
Non-Wood, 8+ Stories, >1939	2983	12	4	0	4872	50	251	22	1	8194
Wood-Frame, 4-7 Stories, <1940, Multi-Family	607	0	2	0	8792	16	3	0	0	9419
Wood-Frame, 4-7 Stories, >1939, Multi-Family	6725	189	201	0	1756	344	354	0	0	9569
Wood-Frame, 1-3 Stories, <1940, Multi-Family	25763	1068	124	10	6054	162	807	224	23	34234
Wood-Frame, 1-3 Stories, >1939, Multi-Family	30431	5990	1227	5	2713	633	7909	369	504	49782
Wood-Frame, 1-3 Stories, <1940, Single Family	4413	428	47	2	187	24	121	40	12	5273
Wood-Frame, 1-3 Stories, >1939, Single Family	1429	384	48	2	20	20	211	15	18	2147
"Other" (tents, caves, boats, etc.)	0	0	0	0	0	0	0	0	0	0
TOTAL	82563	9623	2128	34	38739	1638	13443	1028	892	150087

The damage estimate for an earthquake along the entire Hayward fault represents, by far, the forecast with the most significant housing losses of the eleven estimates outlined in this report. With an area-wide loss of over 150,000 housing units, this scenario is over 70% higher than the northern Hayward event, the next highest damage estimate. An earthquake along the entire Hayward fault would have devastating consequences for the cities in this region. As in the case of the northern and southern Hayward events, Alameda County is again the hardest hit. This time the impact is even greater; over 16% of Alameda County's total housing stock would be uninhabitable.

The impacts on multi-family construction are even more staggering; 37% of Alameda County's multi-family housing stock would be deemed uninhabitable. Over the entire Bay Area, 16% of the multi-family housing stock would not be fit for habitation. Likewise, the devastating damage estimates for unreinforced masonry buildings emphasizes the vulnerability of these buildings -- over the entire Bay Area, almost 55% of them would be uninhabitable, while in Alameda County an astonishing 92% of them would become uninhabitable.

FIGURE -- HOUSING IMPACTS OF AN EARTHQUAKE ON THE ENTIRE HAYWARD FAULT

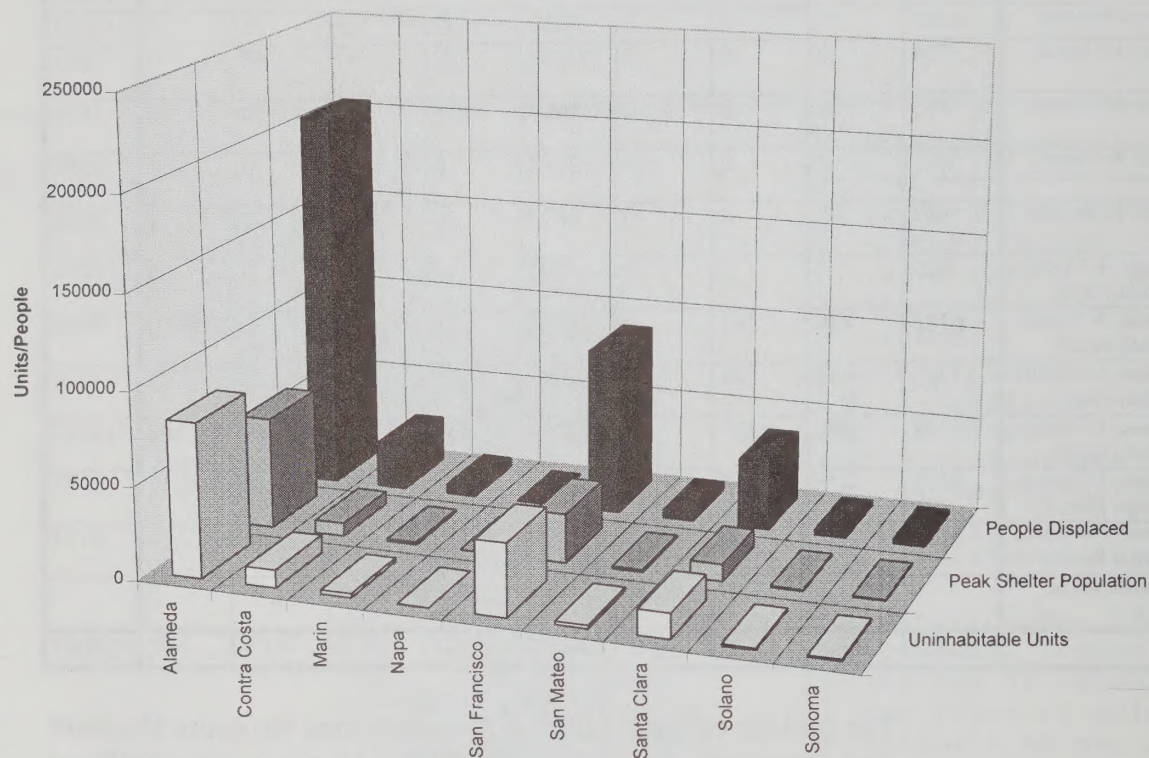


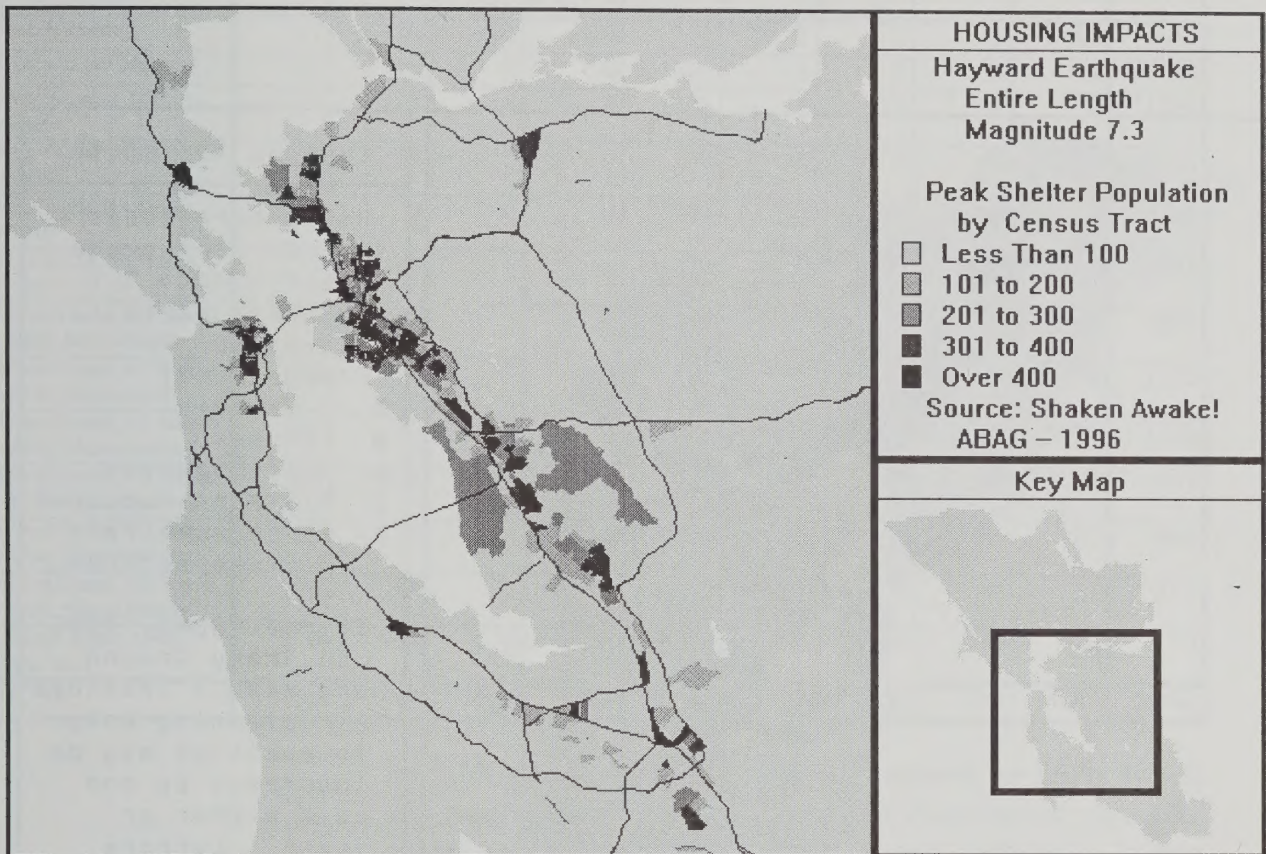
TABLE -- PEOPLE DISPLACED

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Displaced	131456	15476	3243	61	52468	1687	20909	1836	1441	228577
Yellow Tag # People Displaced	73041	9535	2044	26	36186	2728	16318	1091	914	141883
Total # of People Displaced	204497	25011	5287	87	88654	4415	37227	2927	2355	370460

TABLE -- PEAK SHELTER POPULATION

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Sheltered	39403	4493	833	16	15777	464	5299	511	371	67167
Yellow Tag # People Sheltered	20598	2496	484	6	10421	688	3846	282	224	39045
Total Shelter Population	60001	6989	1317	22	26198	1152	9145	793	595	106212

FIGURE -- PEAK SHELTER POPULATION



The effects of an earthquake along the entire length of the Hayward fault would be devastating due to the sheer magnitude of the numbers. Overall, over 370,000 people would be displaced creating a need to shelter over 106,000 people, or the equivalent of the entire population of Berkeley. As in the case of the uninhabitable units, Alameda County is again the hardest hit. Almost 205,000 people in Alameda County would be displaced, creating a need to shelter over 60,000 people in that county alone.

As with the scenarios on the Northern and Southern Hayward fault, the peak shelter population is not limited to the area adjacent to the fault, but is most significant within inner city areas. Again, both Alameda and San Francisco counties are expected to produce the highest percentages of shelter populations relative to their respective displaced population. These counties combined are expected to generate over 81% of the total shelter population.

Healdsburg-Rodgers Creek Earthquake Impacts

This scenario earthquake is for a magnitude 7.1 earthquake on the Healdsburg-Rodgers Creek fault in Sonoma County.

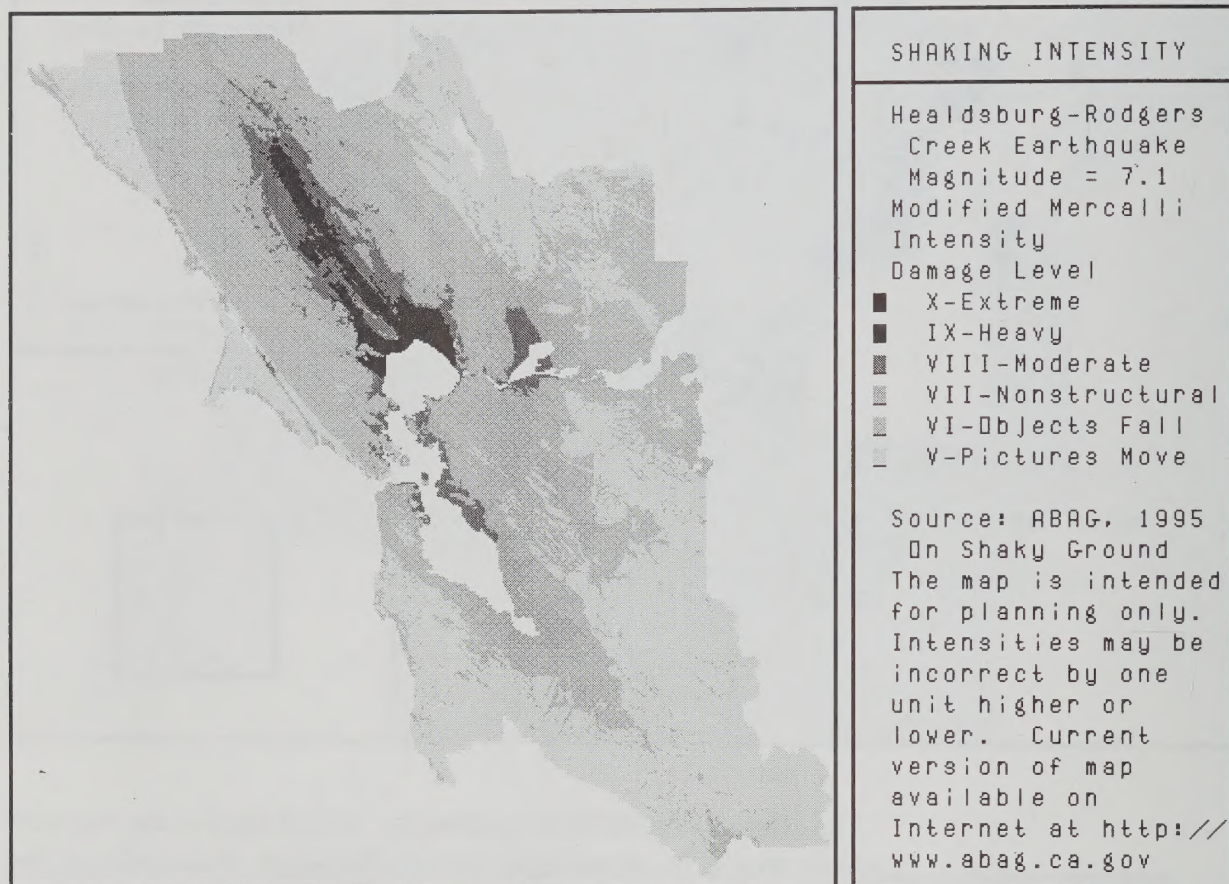


TABLE -- ESTIMATE OF UNINHABITABLE DWELLING UNITS

Construction Type	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Mobile Homes	137	30	195	20	0	2	2	8	6303	6697
Unreinforced Masonry	347	15	8	0	1786	8	2	5	34	2204
Non-Wood, 4-7 Stories, <1940	295	0	0	0	1406	5	13	21	0	1739
Non-Wood, 4-7 Stories, >1939	9	0	0	0	148	0	0	0	58	216
Non-Wood, 8+ Stories, <1940	183	0	0	0	1274	0	5	0	0	1462
Non-Wood, 8+ Stories, >1939	295	1	1	0	1370	0	0	1	327	1994
Wood-Frame, 4-7 Stories, <1940, Multi-Family	67	0	2	0	2598	5	0	0	0	2672
Wood-Frame, 4-7 Stories, >1939, Multi-Family	584	17	119	0	432	17	3	0	0	1172
Wood-Frame, 1-3 Stories, <1940, Multi-Family	501	88	77	13	1523	18	17	45	950	3232
Wood-Frame, 1-3 Stories, >1939, Multi-Family	763	438	772	6	521	13	24	48	5354	7937
Wood-Frame, 1-3 Stories, <1940, Single Family	55	15	27	3	42	4	5	6	307	465
Wood-Frame, 1-3 Stories, >1939, Single Family	20	15	22	3	2	1	0	4	337	404
"Other" (tents, caves, boats, etc.)	0	0	0	0	0	0	0	0	0	0
TOTAL	3256	618	1222	46	11101	71	70	139	13669	30192

As with other earthquakes that are centered on faults which are geographically removed from San Francisco or Alameda counties, the Healdsburg-Rodgers Creek earthquake causes almost as much damage in the County of San Francisco as in Sonoma County, where it is located. However, if the damage numbers for uninhabitability are looked at in terms of percentages of the total local housing stock, the damage is significant for Sonoma County; 8.5% of its local stock would be uninhabitable versus only 3.4% in San Francisco County.

The estimate for San Francisco includes over 11,000 uninhabitable units of which almost 78% were built before 1940. On the other hand, of the estimated 13,669 uninhabitable dwelling units in Sonoma County, only 9% are pre-1940 construction, since in Sonoma County only 11% of the total stock was constructed before 1940. The damage here is expected to occur mainly to mobile homes as 6,303 of them, which represent 53% of their total number, are expected to be uninhabitable.

FIGURE -- HOUSING IMPACTS OF AN EARTHQUAKE ON THE HEALDSBURG-RODGERS CREEK FAULT

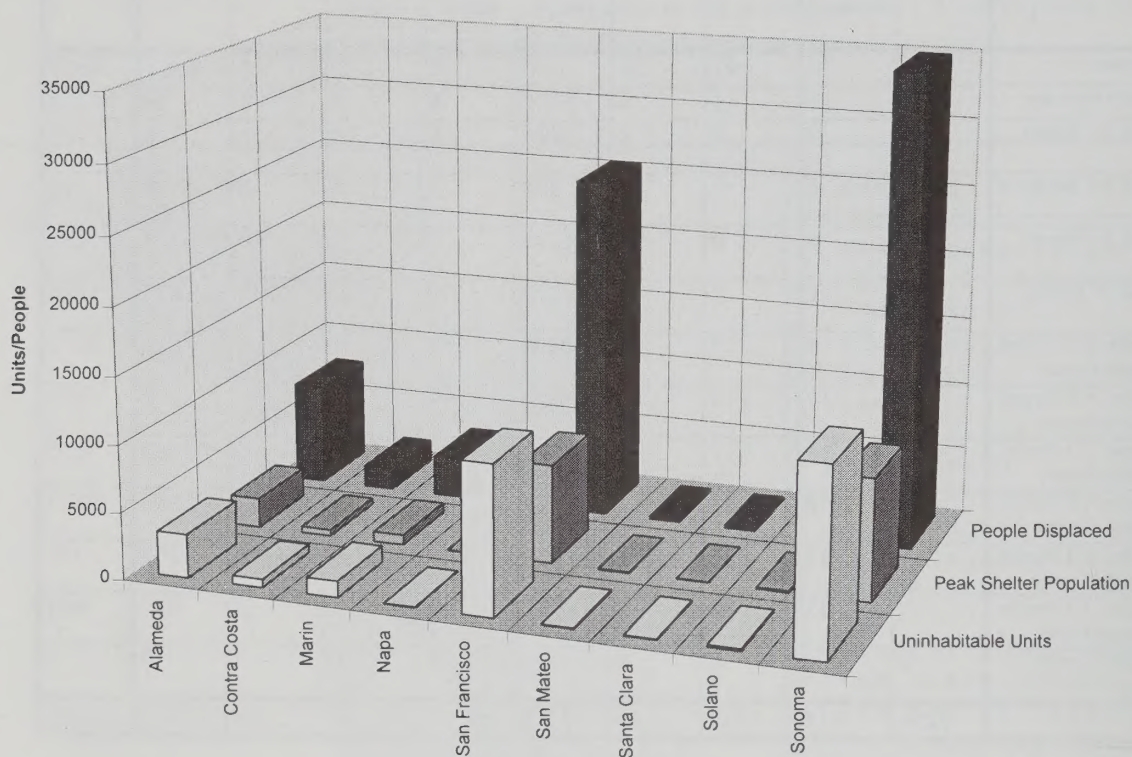


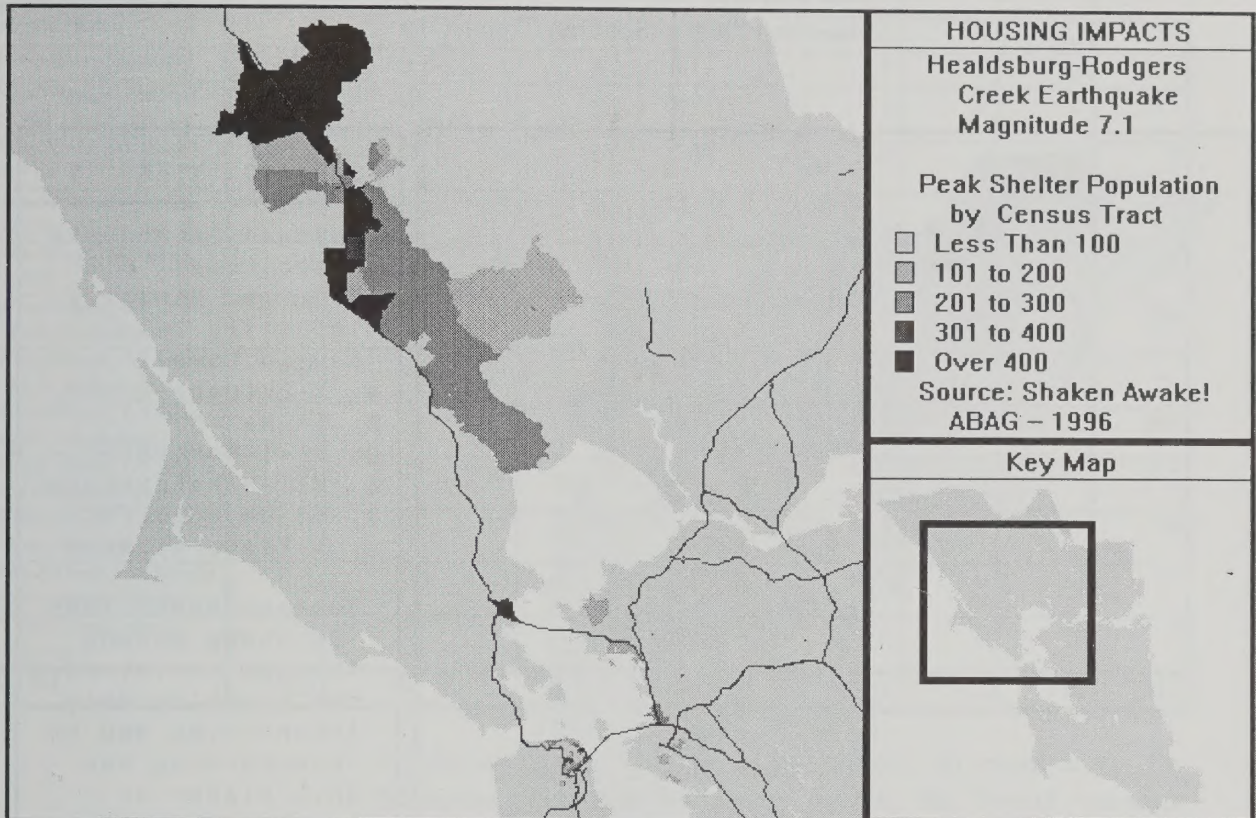
TABLE -- PEOPLE DISPLACED

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Displaced	2800	707	1507	85	7417	50	48	175	26784	39573
Yellow Tag # People Displaced	4819	922	1510	33	17988	133	139	221	8070	33835
Total # of People Displaced	7619	1629	3017	118	25405	183	187	396	34854	73408

TABLE -- PEAK SHELTER POPULATION

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Sheltered	824	207	389	22	2230	12	12	47	7011	10754
Yellow Tag # People Sheltered	1393	250	355	7	5181	33	30	56	2017	9322
Total Shelter Population	2217	457	744	29	7411	45	42	103	9028	20076

FIGURE -- PEAK SHELTER POPULATION



Because the source of the event is located within Sonoma County, shelter needs are largest there, followed by the densely urbanized areas of San Francisco and Alameda counties.

In Sonoma County most of the shelter population is the result of red-tagged dwelling units (78%), while in San Francisco and Alameda counties most is the result of yellow-tagged units (70% and 63% respectively). This difference is the result of the impact of demographic factors in the output of shelter populations, particularly income and household type. While in San Francisco County most of the uninhabitable dwelling units are within multi-family buildings, in Sonoma County only half of them are in these buildings. The probability of individuals seeking shelter in the event of a major earthquake will be higher to residents of multi-family buildings within San Francisco and Alameda counties.

Maacama Earthquake Impacts

This scenario earthquake is for a magnitude 6.8 earthquake on the Maacama fault in Sonoma County.

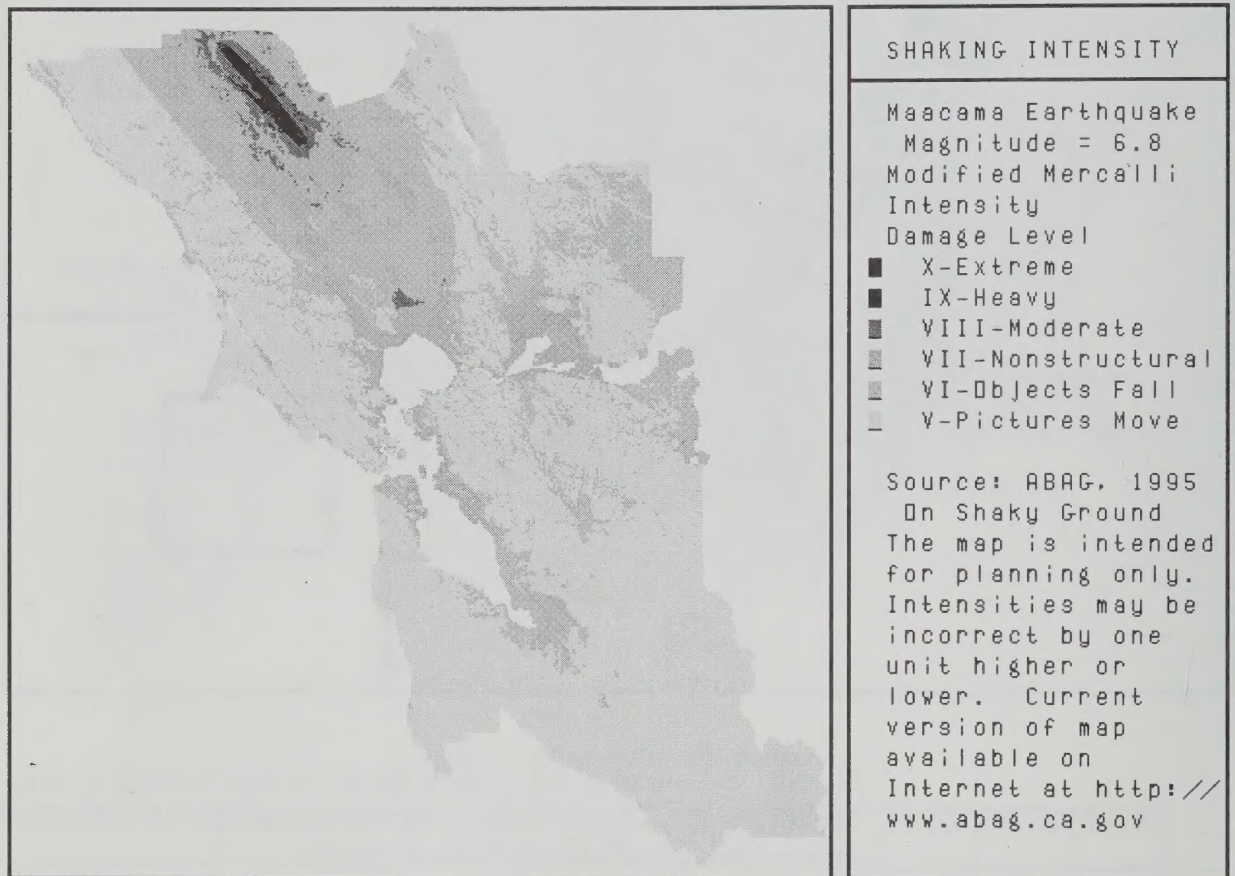


TABLE -- ESTIMATE OF UNINHABITABLE DWELLING UNITS

Construction Type	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Mobile Homes	3	0	2	7	0	0	0	1	462	475
Unreinforced Masonry	88	3	1	0	601	3	0	2	6	703
Non-Wood, 4-7 Stories, <1940	58	0	0	0	249	0	1	3	0	311
Non-Wood, 4-7 Stories, >1939	0	0	0	0	0	0	0	0	0	0
Non-Wood, 8+ Stories, <1940	40	0	0	0	222	0	0	0	0	262
Non-Wood, 8+ Stories, >1939	14	0	0	0	72	0	0	0	17	103
Wood-Frame, 4-7 Stories, <1940, Multi-Family	13	0	0	0	617	0	0	0	0	630
Wood-Frame, 4-7 Stories, >1939, Multi-Family	47	2	11	0	22	1	0	0	0	83
Wood-Frame, 1-3 Stories, <1940, Multi-Family	42	4	5	8	183	2	1	5	52	301
Wood-Frame, 1-3 Stories, >1939, Multi-Family	12	7	6	3	10	3	9	4	191	245
Wood-Frame, 1-3 Stories, <1940, Single Family	7	1	2	4	11	1	1	1	47	74
Wood-Frame, 1-3 Stories, >1939, Single Family	1	0	0	1	0	0	0	0	23	27
"Other" (tents, caves, boats, etc.)	0	0	0	0	0	0	0	0	0	0
TOTAL	325	17	27	22	1986	11	11	15	798	3212

Of the estimates outlined in this report, an event along the Maacama fault seems to have, overall, the lowest damage forecasts. A total of 3,212 dwelling units, which represents only 0.1% of the total Bay Area housing stock, would be deemed uninhabitable.

The damage estimate is highest in San Francisco County, where almost 2,000 uninhabitable units, or 62% of the total Bay Area uninhabitable units during this event, would exist. In Sonoma County, the next hardest hit area during this event, most of the damage would occur to mobile homes; they represent 58% of the total uninhabitable units estimated for that county.

FIGURE -- HOUSING IMPACTS OF AN EARTHQUAKE ON THE MAACAMA FAULT

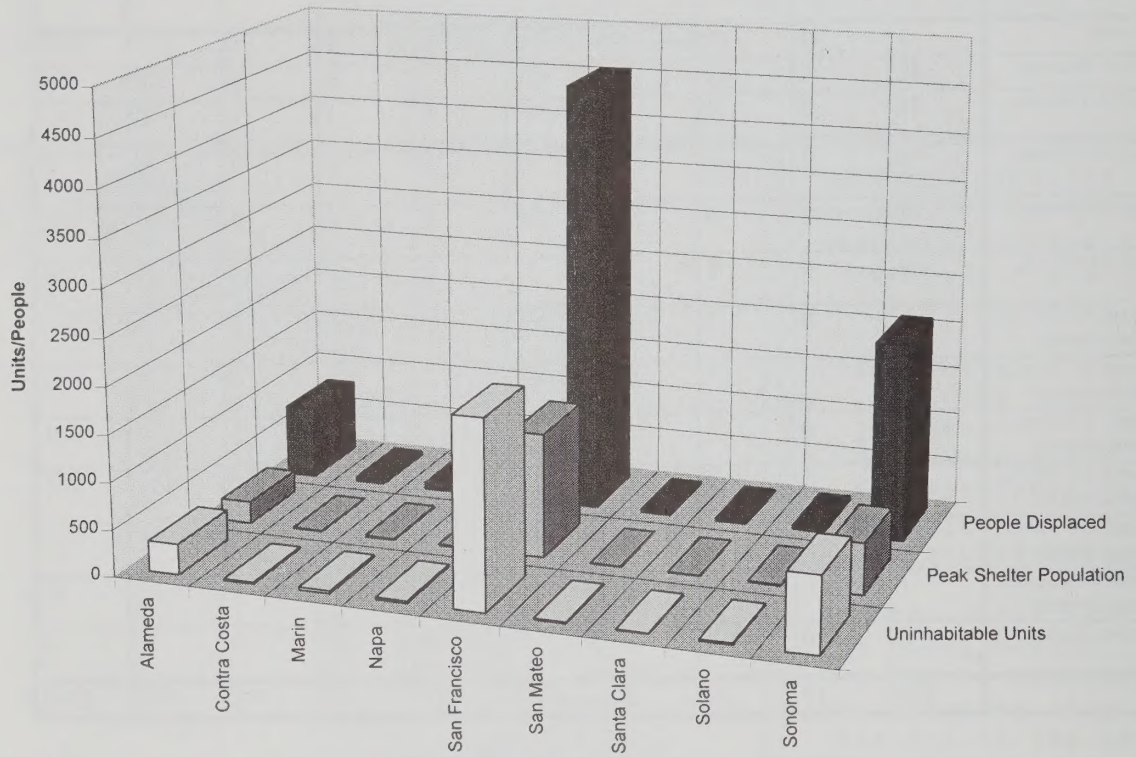


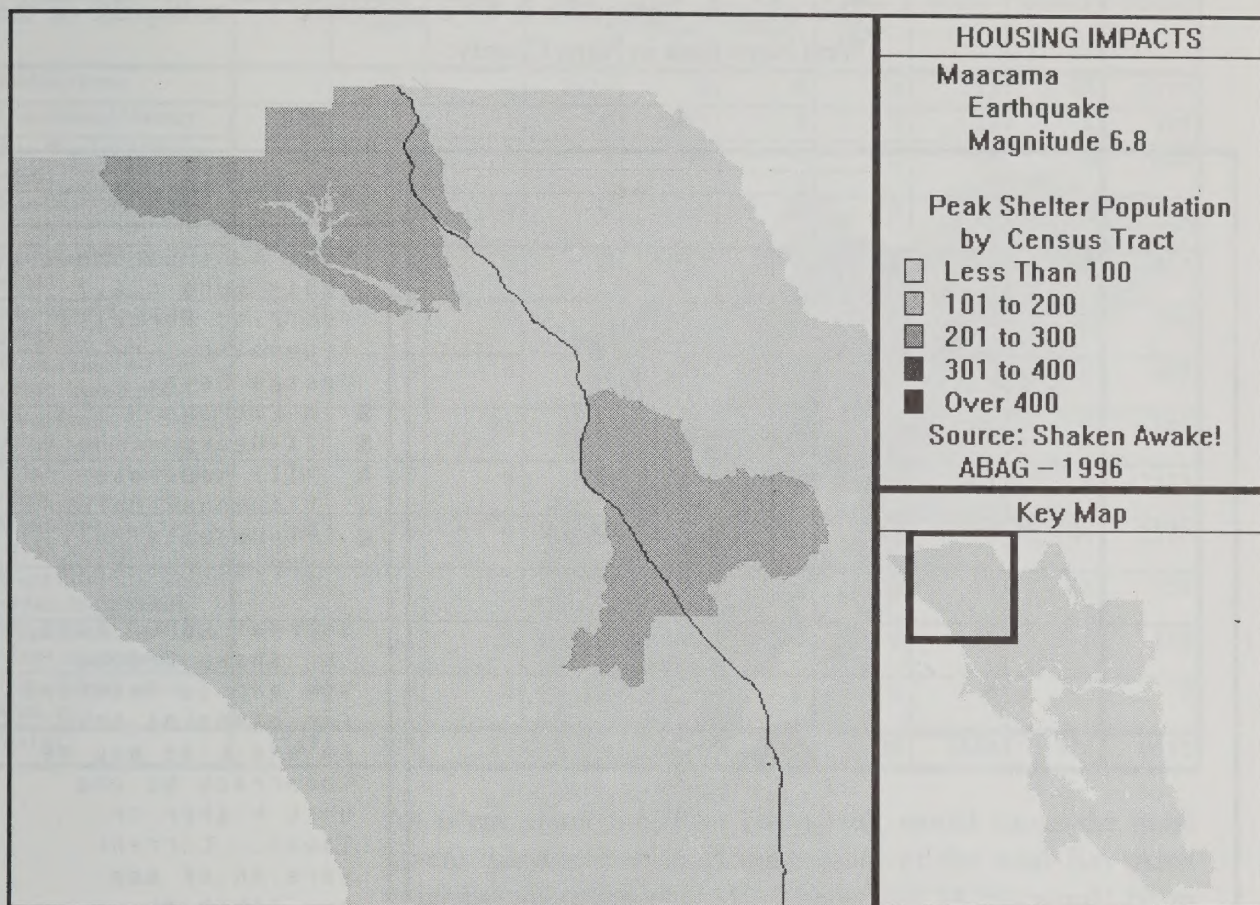
TABLE -- PEOPLE DISPLACED

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Displaced	103	11	18	38	826	3	4	12	1653	2668
Yellow Tag # People Displaced	679	32	49	19	3720	23	26	30	440	5018
Total # of People Displaced	782	43	67	57	4546	26	30	42	2093	7686

TABLE -- PEAK SHELTER POPULATION

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Sheltered	31	1	3	10	248	0	0	3	434	730
Yellow Tag # People Sheltered	204	6	10	4	1071	4	6	7	110	1422
Total Shelter Population	235	7	13	14	1319	4	6	10	544	2152

FIGURE -- PEAK SHELTER POPULATION

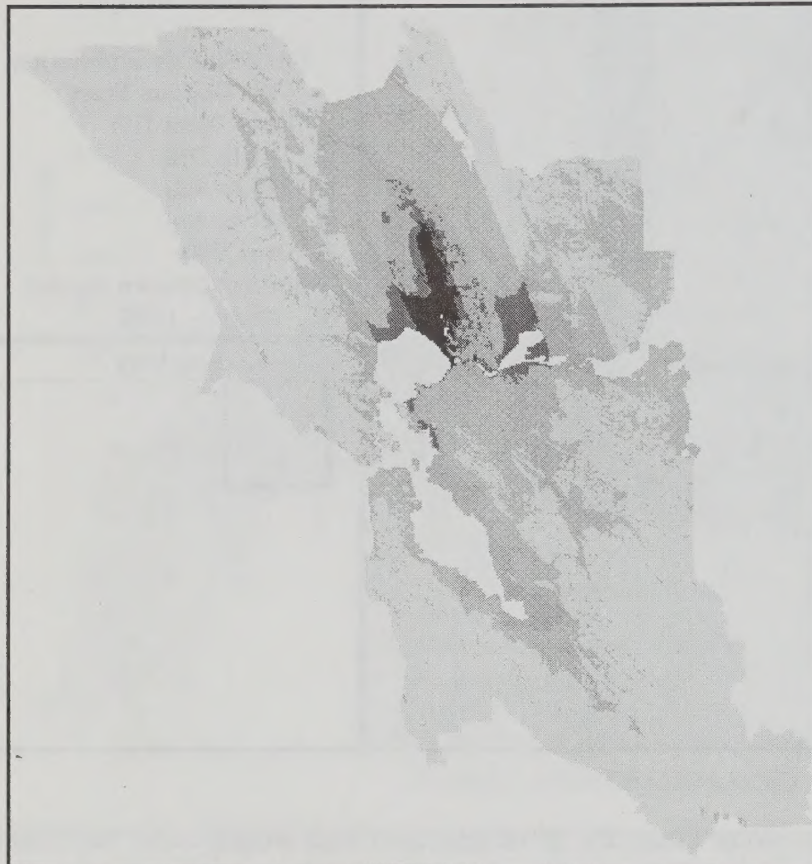


An event along the Maacama fault line would cause the largest numbers of displaced and shelter populations in San Francisco County. Over 61% of the total peak shelter population is expected to be from San Francisco County, while only 25% is expected to be from Sonoma County.

In Sonoma County, 80% of the shelter population is a result of uninhabitable **red**-tagged dwelling units; in San Francisco County, 81% of the shelter population is a result of uninhabitable **yellow**-tagged units. Since in San Francisco County 99% of the uninhabitable dwelling units are within multi-family buildings, it appears that individuals that reside within inner city multi-family buildings that are yellow tagged have a high likelihood of going to a shelter in the event of a major earthquake.

West Napa Earthquake Impacts

This scenario earthquake is for a magnitude 6.7 earthquake on the West Napa fault in Napa County.



SHAKING INTENSITY

West Napa Earthquake
Magnitude = 6.7
Modified Mercalli
Intensity
Damage Level

- X-Extreme
- IX-Heavy
- VIII-Moderate
- VII-Nonstructural
- VI-Objects Fall
- V-Pictures Move

Source: ABAG, 1995
On Shaky Ground
The map is intended
for planning only.
Intensities may be
incorrect by one
unit higher or
lower. Current
version of map
available on
Internet at <http://www.abag.ca.gov>

TABLE -- ESTIMATE OF UNINHABITABLE DWELLING UNITS

Construction Type	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Mobile Homes	5	23	2	1829	0	0	0	392	63	2315
Unreinforced Masonry	279	11	1	0	601	4	1	28	4	929
Non-Wood, 4-7 Stories, <1940	286	0	0	0	249	0	1	68	0	604
Non-Wood, 4-7 Stories, >1939	0	0	0	0	0	0	0	0	0	0
Non-Wood, 8+ Stories, <1940	177	0	0	0	222	0	4	0	0	403
Non-Wood, 8+ Stories, >1939	111	1	0	0	72	0	0	22	0	206
Wood-Frame, 4-7 Stories, <1940, Multi-Family	57	0	0	0	626	0	0	0	0	683
Wood-Frame, 4-7 Stories, >1939, Multi-Family	136	8	11	0	22	2	0	0	0	180
Wood-Frame, 1-3 Stories, <1940, Multi-Family	252	54	6	530	192	3	8	261	8	1313
Wood-Frame, 1-3 Stories, >1939, Multi-Family	45	166	6	1497	11	5	13	789	44	2577
Wood-Frame, 1-3 Stories, <1940, Single Family	28	11	2	138	16	1	3	54	4	256
Wood-Frame, 1-3 Stories, >1939, Single Family	4	11	0	134	0	0	0	36	3	188
"Other" (tents, caves, boats, etc.)	0	0	0	0	0	0	0	0	0	0
TOTAL	1382	284	27	4129	2011	15	29	1650	126	9652

An event along the West Napa fault would cause the most severe damage in Napa County. Out of the total Bay Area uninhabitable units of 9,652, almost half (43%) would be in Napa County. San Francisco, Alameda, and Solano counties would share the majority of the rest of the damage.

As is the case with previous events, the older housing stock in Alameda and San Francisco counties would experience the most damage. In the more recently urbanized counties of Napa and Solano, on the other hand, most of the damage would be experienced by mobile homes and one-to-three story wood-frame buildings.

FIGURE -- HOUSING IMPACTS OF AN EARTHQUAKE ON THE WEST NAPA FAULT

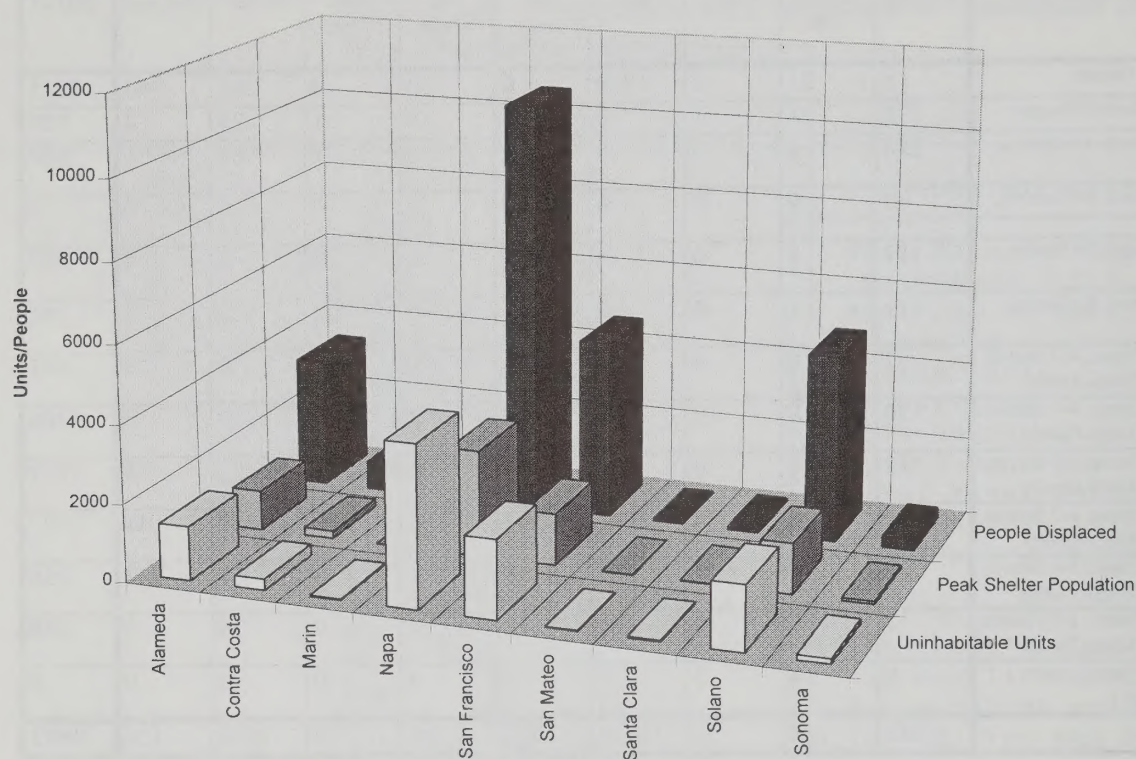


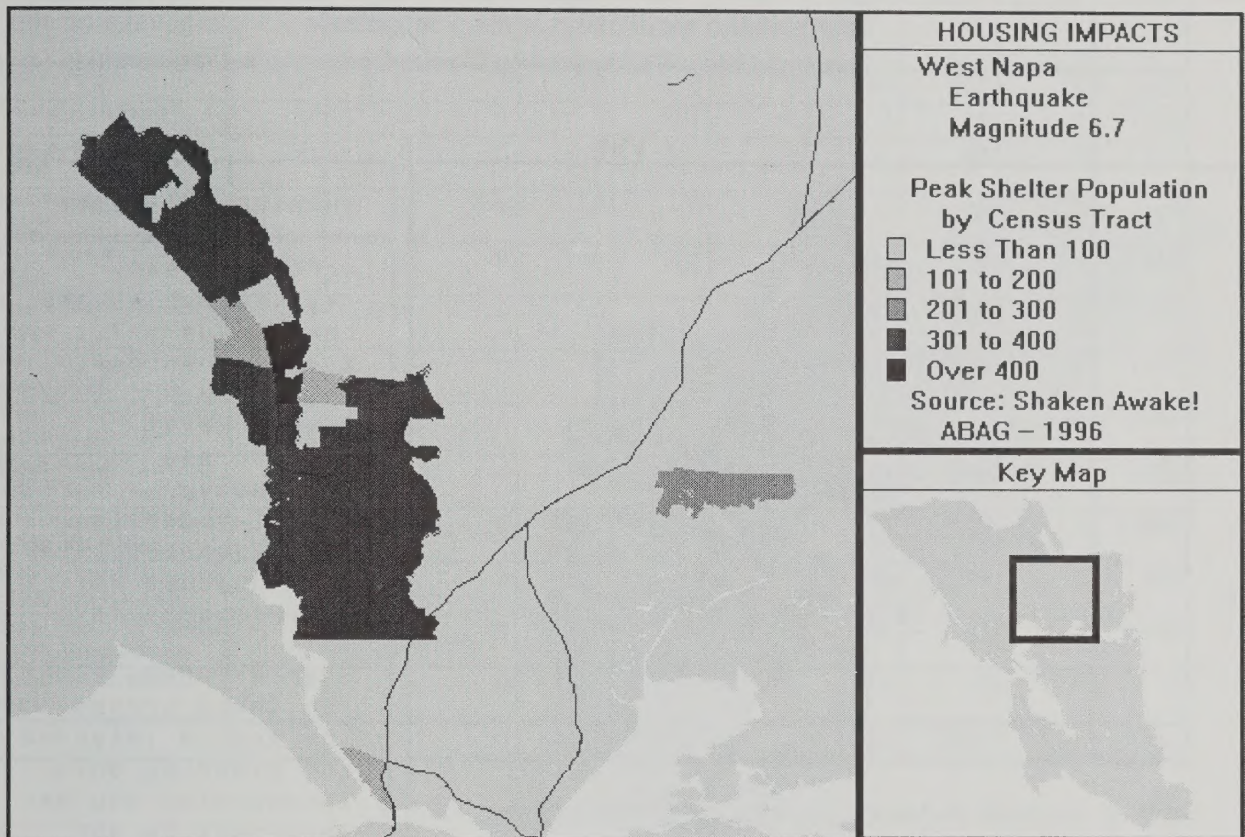
TABLE -- PEOPLE DISPLACED

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Displaced	736	342	19	8281	853	6	17	2855	204	13313
Yellow Tag # People Displaced	2617	396	49	2289	3749	32	63	1939	80	11214
Total # of People Displaced	3353	738	68	10570	4602	38	80	4794	284	24527

TABLE -- PEAK SHELTER POPULATION

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Sheltered	233	90	3	2164	256	0	3	789	53	3591
Yellow Tag # People Sheltered	797	101	11	572	1080	6	14	495	19	3095
Total Shelter Population	1030	191	14	2736	1336	6	17	1284	72	6686

FIGURE -- PEAK SHELTER POPULATION



Napa County is clearly the hardest hit county in both gross numbers and percentages. Over twice as many people from Napa County are expected to be displaced than from San Francisco, and over three times than from Alameda County. Similarly, Napa County's peak shelter population is larger than Alameda and San Francisco counties combined. Over 40% of this event's displaced and peak shelter populations is expected to be from Napa County.

Within Napa County, 79% of the projected shelter population is a result of red-tagged dwelling units, and most (over 80% of the uninhabitable dwelling units) are either mobile homes or 1-3 story post-1939 multi-family buildings. These relationships alone are not enough to prove a correlation between uninhabitable mobile homes, multi-family dwelling units and the generation of shelter populations. However they do seem to suggest an association between certain housing types and the probability of going to a shelter in the event of a major earthquake.

Concord-Green Valley Scenario Impacts

This scenario earthquake is for a magnitude 7.1 earthquake on the Concord-Green Valley fault in Contra Costa and Solano counties.

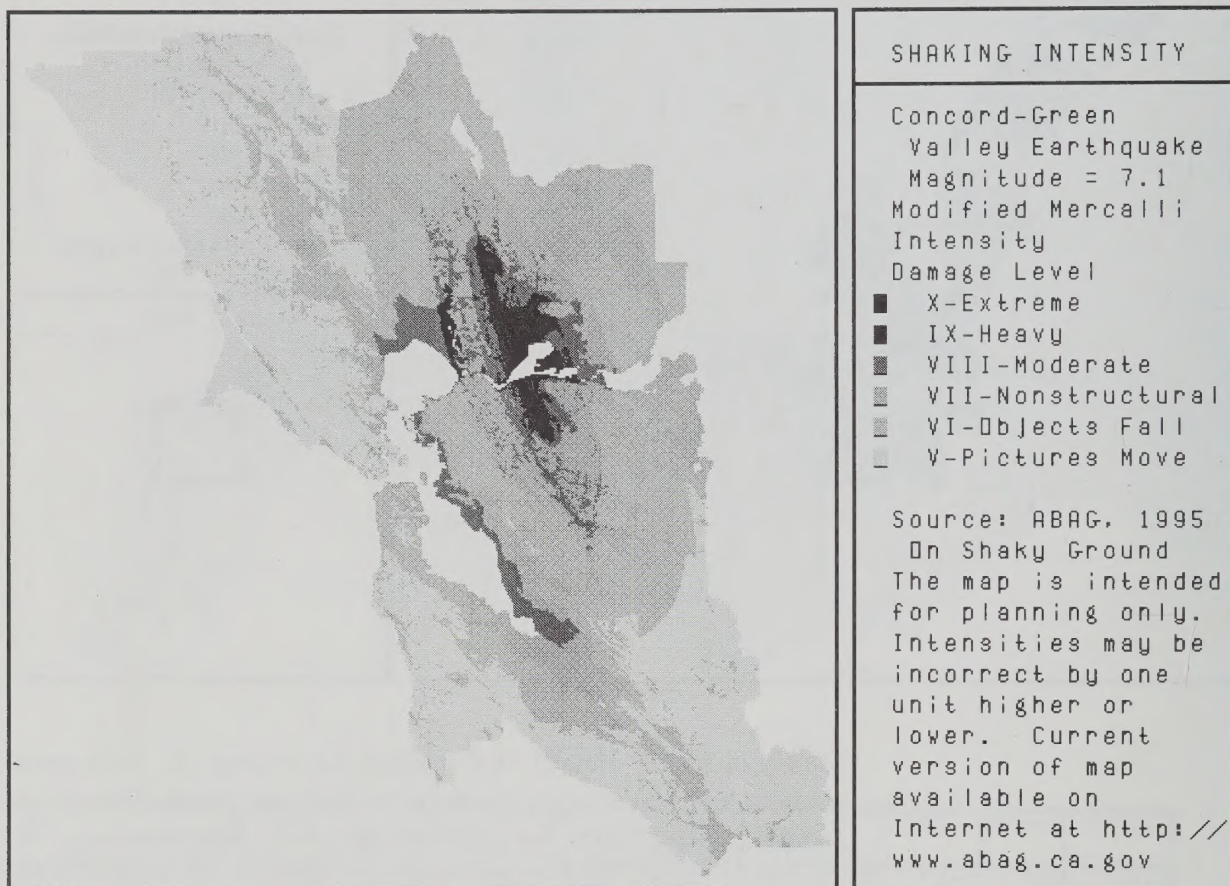


TABLE -- ESTIMATE OF UNINHABITABLE DWELLING UNITS

Construction Type	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Mobile Homes	155	2351	2	470	0	2	62	602	16	3660
Unreinforced Masonry	359	18	1	0	801	8	3	28	2	1220
Non-Wood, 4-7 Stories, <1940	295	0	0	0	355	5	13	68	0	735
Non-Wood, 4-7 Stories, >1939	9	0	0	0	0	0	0	0	0	9
Non-Wood, 8+ Stories, <1940	183	0	0	0	242	0	23	0	0	448
Non-Wood, 8+ Stories, >1939	294	229	0	0	146	0	18	22	0	709
Wood-Frame, 4-7 Stories, <1940, Multi-Family	69	0	0	0	1084	5	1	0	0	1157
Wood-Frame, 4-7 Stories, >1939, Multi-Family	612	831	11	0	85	18	34	0	0	1590
Wood-Frame, 1-3 Stories, <1940, Multi-Family	554	398	6	119	435	19	73	344	4	1952
Wood-Frame, 1-3 Stories, >1939, Multi-Family	921	7859	6	537	21	13	76	1619	8	11060
Wood-Frame, 1-3 Stories, <1940, Single Family	59	105	2	28	22	4	10	89	3	322
Wood-Frame, 1-3 Stories, >1939, Single Family	38	403	0	20	1	1	12	93	2	569
"Other" (tents, caves, boats, etc.)	0	0	0	0	0	0	0	0	0	0
TOTAL	3546	12195	28	1173	3191	74	324	2865	35	23431

Unlike most of the other forecast scenarios outlined in this report in which the counties with the older housing stocks experience the most damage, during an event along the Concord-Green Valley fault, Contra Costa County would experience the most severe damage. Out of the total Bay Area damage of 23,431 uninhabitable dwelling units, 52% of these would occur in Contra Costa County.

In Contra Costa County, post-1939 single family dwellings and post-1939 under three story apartments are the two most common forms of housing. Together they account for almost 90% of the total stock for Contra Costa County. Of these two housing types, post-1939 one-to-three story multi-family dwellings account for most of the uninhabitable units in this earthquake scenario. In Contra Costa County, dwellings in this type of construction would account for 64% of the overall local housing that is uninhabitable.

FIGURE -- HOUSING IMPACTS OF AN EARTHQUAKE ON THE CONCORD - GREEN VALLEY FAULT

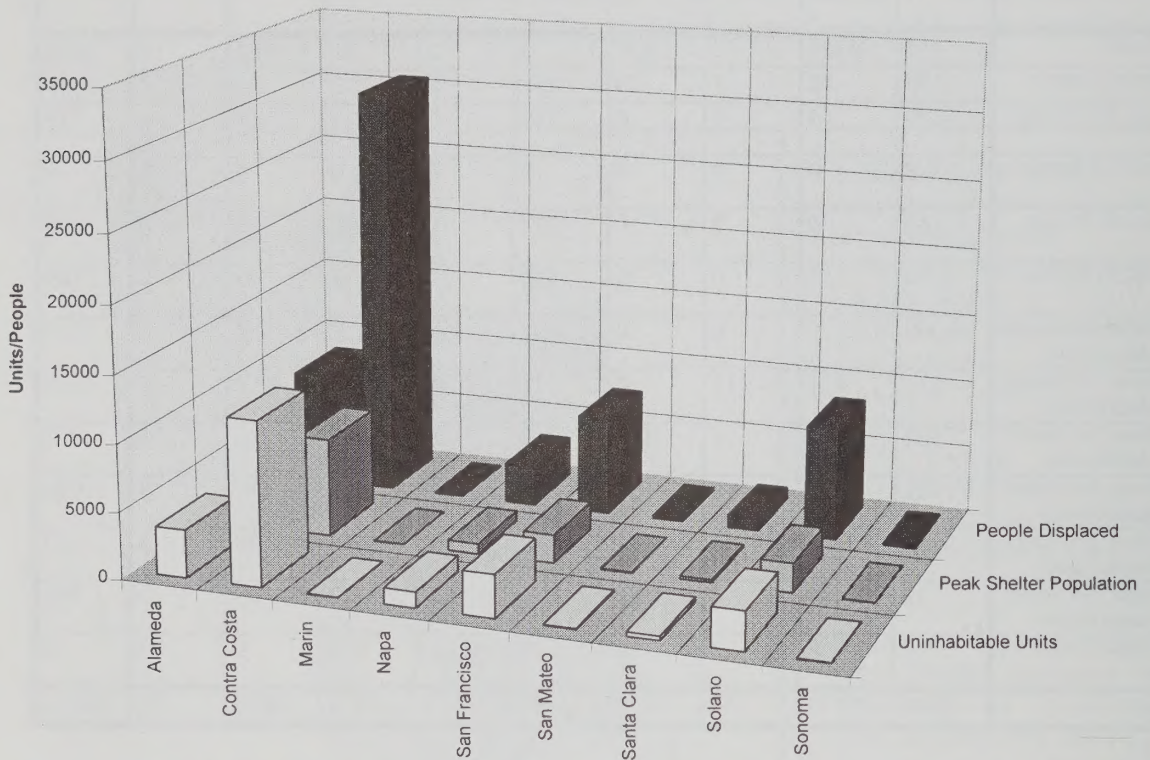


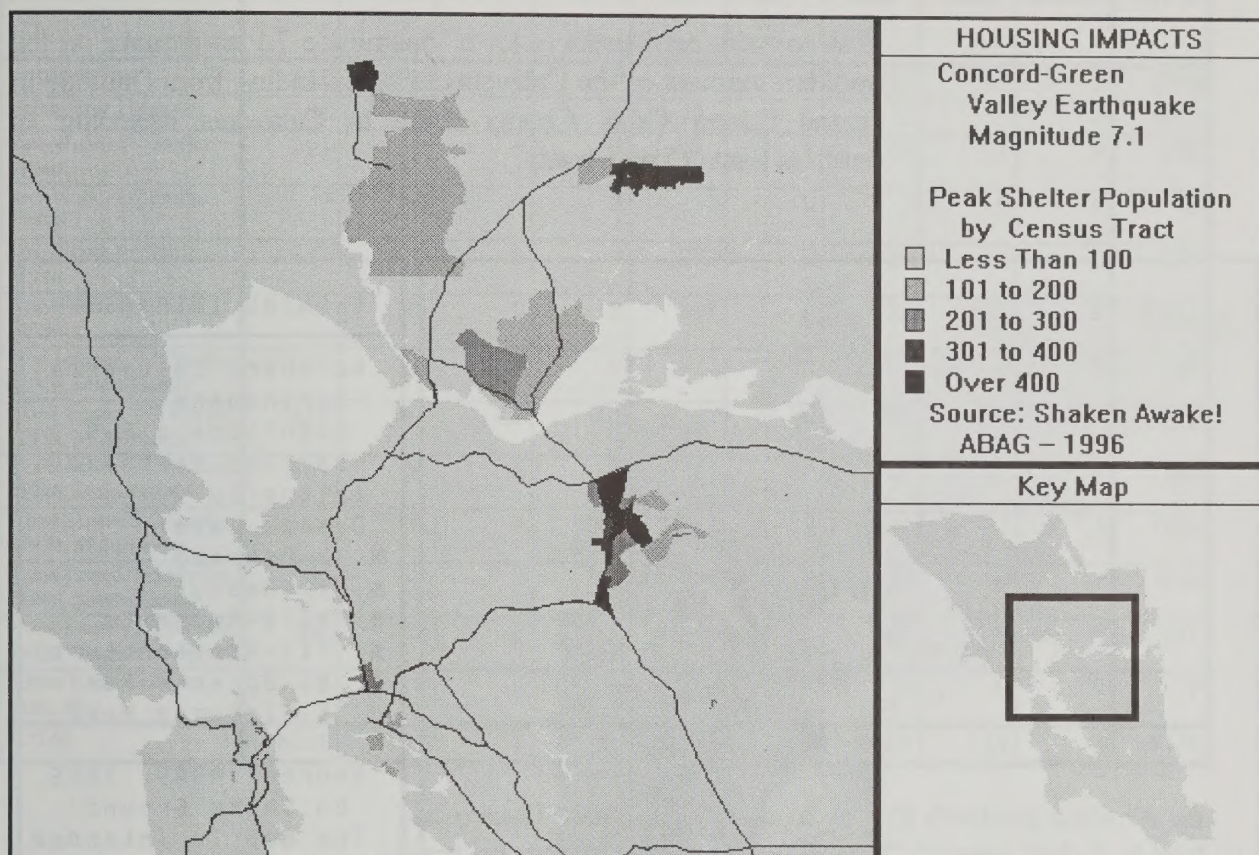
TABLE -- PEOPLE DISPLACED

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Displaced	3123	18552	19	2006	1502	55	375	4940	61	30633
Yellow Tag # People Displaced	5278	11992	50	997	5801	138	513	3413	28	28210
Total # of People Displaced	8401	30544	69	3003	7303	193	888	8353	89	58843

TABLE -- PEAK SHELTER POPULATION

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Sheltered	909	4623	3	520	452	14	96	1324	16	7957
Yellow Tag # People Sheltered	1506	2719	11	248	1671	34	120	848	6	7163
Total Shelter Population	2415	7342	14	768	2123	48	216	2172	22	15120

FIGURE -- PEAK SHELTER POPULATION



Contra Costa County is expected to generate the largest numbers of both displaced populations (52% of the total) and of shelter populations (49% of the total). The majority of the shelter population in Contra Costa County (63%) would be generated by red-tagged dwelling units.

The pattern of a higher percentage of red-tagged generated shelter-seeking population seems to be followed by some of the other suburban counties, such as Napa, Solano and Sonoma counties. In each of these cases, 68%, 61%, and 73% of the total peak shelter population respectively, is generated by red-tagged units. On the other hand, in the more densely urbanized counties of Alameda and San Francisco, the majority of the shelter-seeking population is expected to come from yellow-tagged dwelling units -- 62% in Alameda County and 79% in San Francisco County. Because of demographic factors and because of their housing stock, it appears that the older and more densely populated counties are likely to generate shelter populations with less severe damage to their buildings.

Northern Calaveras Earthquake Impacts

This scenario earthquake is for a magnitude 7.1 earthquake on the northern segment of the Calaveras fault, extending from Danville in central Contra Costa County south to Calaveras Reservoir in northern Santa Clara County.

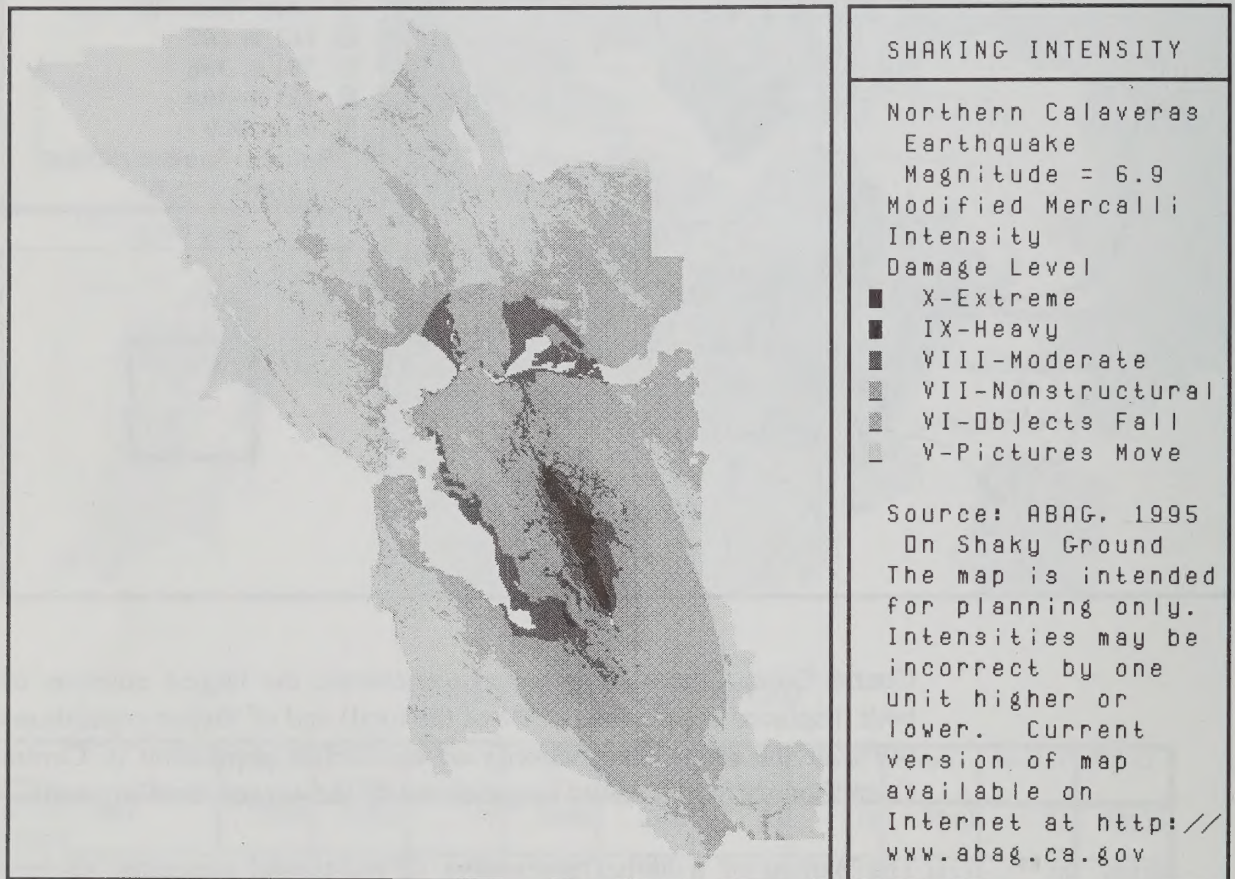


TABLE -- ESTIMATE OF UNINHABITABLE DWELLING UNITS

Construction Type	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Mobile Homes	452	514	2	3	0	2	705	10	0	1688
Unreinforced Masonry	361	9	1	0	773	7	3	5	1	1159
Non-Wood, 4-7 Stories, <1940	293	0	0	0	281	1	13	21	0	608
Non-Wood, 4-7 Stories, >1939	9	0	0	0	0	0	2	0	0	12
Non-Wood, 8+ Stories, <1940	183	0	0	0	242	0	29	0	0	454
Non-Wood, 8+ Stories, >1939	298	20	0	0	105	0	22	1	0	445
Wood-Frame, 4-7 Stories, <1940, Multi-Family	67	0	0	0	673	2	1	0	0	743
Wood-Frame, 4-7 Stories, >1939, Multi-Family	610	501	11	0	33	16	58	0	0	1228
Wood-Frame, 1-3 Stories, <1940, Multi-Family	587	90	6	7	217	15	146	41	1	1108
Wood-Frame, 1-3 Stories, >1939, Multi-Family	3015	2768	5	3	13	12	1431	47	2	7296
Wood-Frame, 1-3 Stories, <1940, Single Family	95	18	2	1	17	3	22	6	1	166
Wood-Frame, 1-3 Stories, >1939, Single Family	262	195	0	1	0	1	58	4	0	521
"Other" (tents, caves, boats, etc.)	0	0	0	0	0	0	0	0	0	0
TOTAL	6231	4114	27	15	2354	58	2490	134	5	15428

The overall damage estimate of 15,428 dwelling units for an event on the northern portion of the Calaveras fault is shared mainly between Alameda, Contra Costa, San Francisco, and Santa Clara counties. The impacts would be most severely felt in Alameda County, as 40% of the uninhabitable dwelling units would be located within this county. As with the southern portion of the Hayward fault which impacts a similar latitude of Alameda County, post-1939 wood frame housing three stories and under would account for the highest percentage of the total damaged units. This type of construction is also the most commonly impacted in Contra Costa County.

FIGURE --HOUSING IMPACTS OF AN EARTHQUAKE ON THE NORTHERN CALAVERAS FAULT

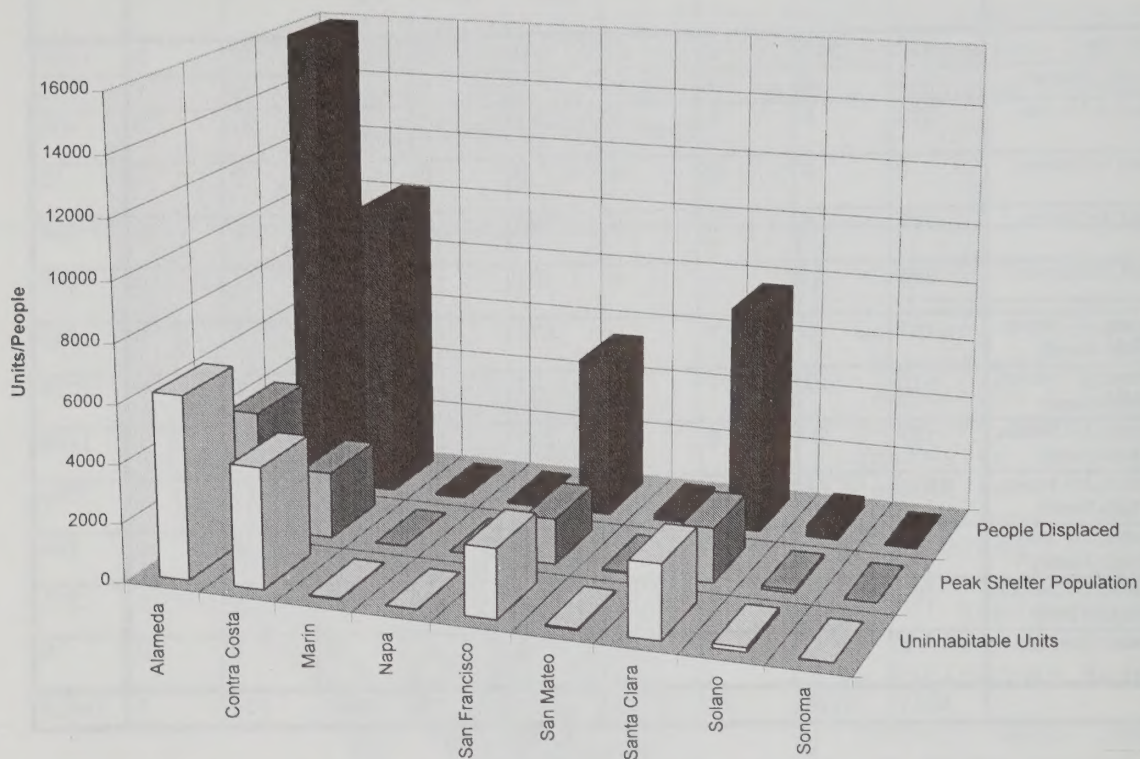


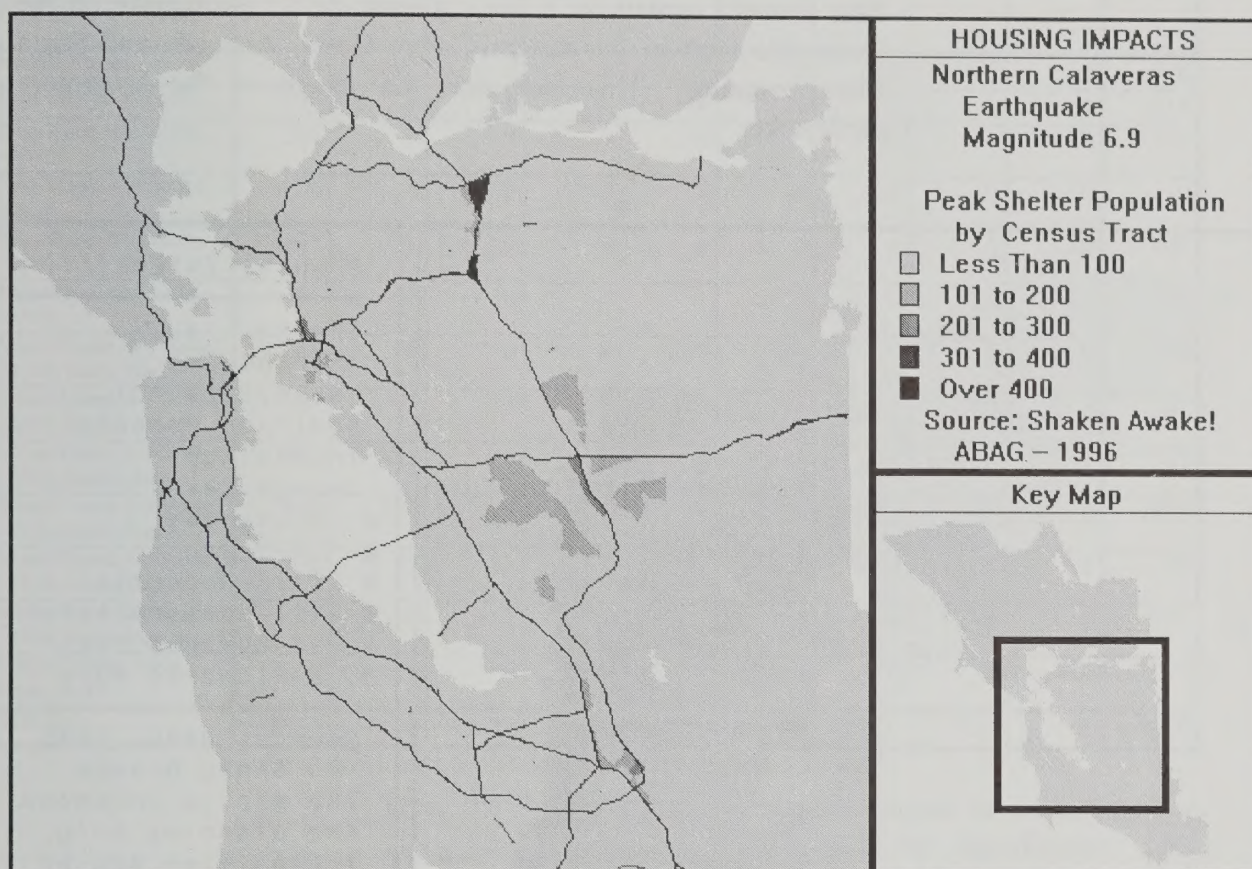
TABLE -- PEOPLE DISPLACED

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Displaced	7293	5007	18	21	1111	44	4189	172	3	17858
Yellow Tag # People Displaced	8628	5136	48	17	4276	110	3456	212	8	21891
Total # of People Displaced	15921	10143	66	38	5387	154	7645	384	11	39749

TABLE -- PEAK SHELTER POPULATION

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Sheltered	1880	1171	3	5	334	12	1066	48	0	4519
Yellow Tag # People Sheltered	2215	1090	11	4	1231	27	800	54	0	5432
Total Shelter Population	4095	2261	14	9	1565	39	1866	102	0	9951

FIGURE -- PEAK SHELTER POPULATION



An event along the northern portion of the Calaveras fault would have the most significant housing impacts in Alameda County. Over 41% of the total shelter population would come from Alameda County alone. The expected peak shelter population is over 81% greater in Alameda County than in Contra Costa County and over two times greater than in Santa Clara County. This relationship is because the projected uninhabitable dwelling units in Alameda County are greater and also because of demographic factors. While in Alameda County the ratio between uninhabitable dwelling units and peak shelter population is 1.52, in Santa Clara County this ratio is 1.33 -- a greater number of uninhabitable dwelling units per each shelter-seeking individual is projected in Santa Clara County than in Alameda County.

In addition, the pattern described in the previous scenarios in which in the older and denser counties appear to generate shelter populations with less severe damage to their buildings is repeated here. This pattern is particularly evident when comparing San Francisco and Santa Clara counties' yellow and red-tagged peak shelter populations -- in San Francisco 79% would come from yellow-tagged buildings while in Santa Clara County the equivalent number is only 43%.

Greenville Earthquake Impacts

This scenario earthquake is for a magnitude 7.1 earthquake on the Greenville fault in far eastern Contra Costa, Alameda and Santa Clara counties. This fault was the source of the Livermore earthquake.

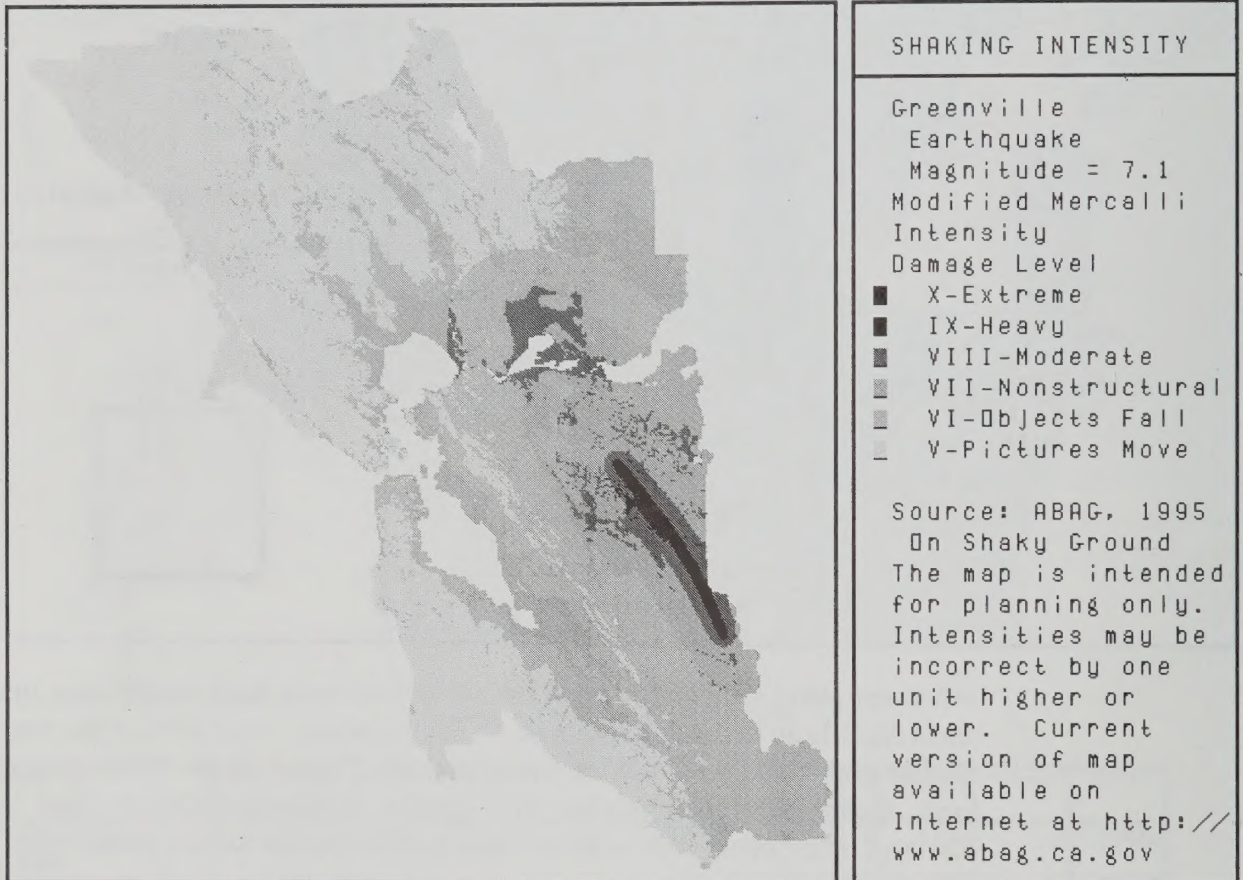


TABLE -- ESTIMATE OF UNINHABITABLE DWELLING UNITS

Construction Type	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Mobile Homes	215	692	2	3	0	0	19	43	0	974
Unreinforced Masonry	275	16	1	0	48	4	2	5	1	351
Non-Wood, 4-7 Stories, <1940	286	0	0	0	9	0	13	21	0	330
Non-Wood, 4-7 Stories, >1939	0	0	0	0	0	0	0	0	0	0
Non-Wood, 8+ Stories, <1940	177	0	0	0	8	0	5	0	0	191
Non-Wood, 8+ Stories, >1939	91	12	0	0	1	0	0	1	0	105
Wood-Frame, 4-7 Stories, <1940, Multi-Family	48	0	0	0	378	0	0	0	0	426
Wood-Frame, 4-7 Stories, >1939, Multi-Family	107	77	11	0	3	2	7	0	0	207
Wood-Frame, 1-3 Stories, <1940, Multi-Family	239	123	6	7	108	3	26	58	1	571
Wood-Frame, 1-3 Stories, >1939, Multi-Family	888	739	5	3	7	6	38	182	2	1871
Wood-Frame, 1-3 Stories, <1940, Single Family	38	27	2	1	14	1	5	8	1	98
Wood-Frame, 1-3 Stories, >1939, Single Family	47	48	0	1	0	0	6	6	0	107
"Other" (tents, caves, boats, etc.)	0	0	0	0	0	0	0	0	0	0
TOTAL	2413	1734	27	14	576	16	120	324	5	5230

Over the Bay Area as a whole, the impact of an earthquake along the Greenville fault would be significantly less devastating than events along the Hayward or Healdsburg-Rodgers Creek faults. Of the estimates outlined in this report, the total damage forecasts for an event along the Greenville fault are the next to lowest ones. Of the total number of uninhabitable dwelling units of 5,230, almost 80% of these are located in Alameda or Contra Costa counties.

Although the fault is geographically located within the eastern-most sections of Alameda, Contra Costa, and Santa Clara counties, the damage forecast for San Francisco County is still high. Overall, the construction types accounting for most of the uninhabitable units are 1-3 story wood-frame multi-family built after 1939 (36%) and mobile homes (19%).

FIGURE --HOUSING IMPACTS OF AN EARTHQUAKE ON THE GREENVILLE FAULT

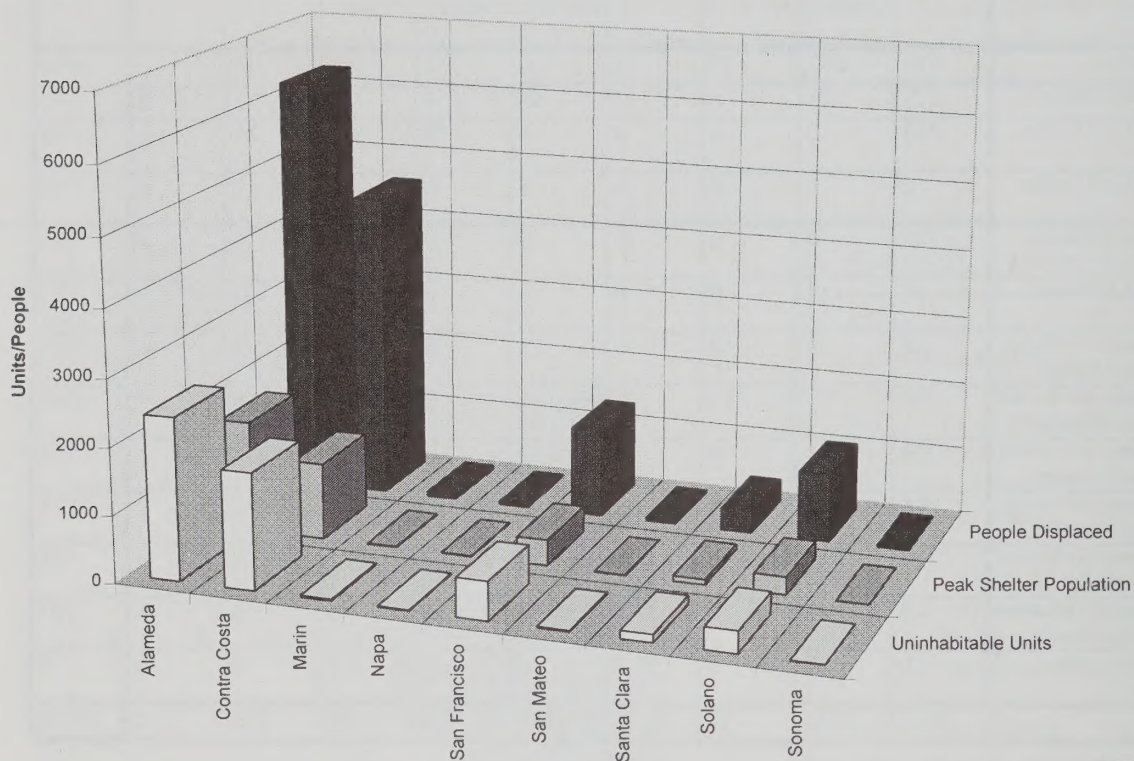


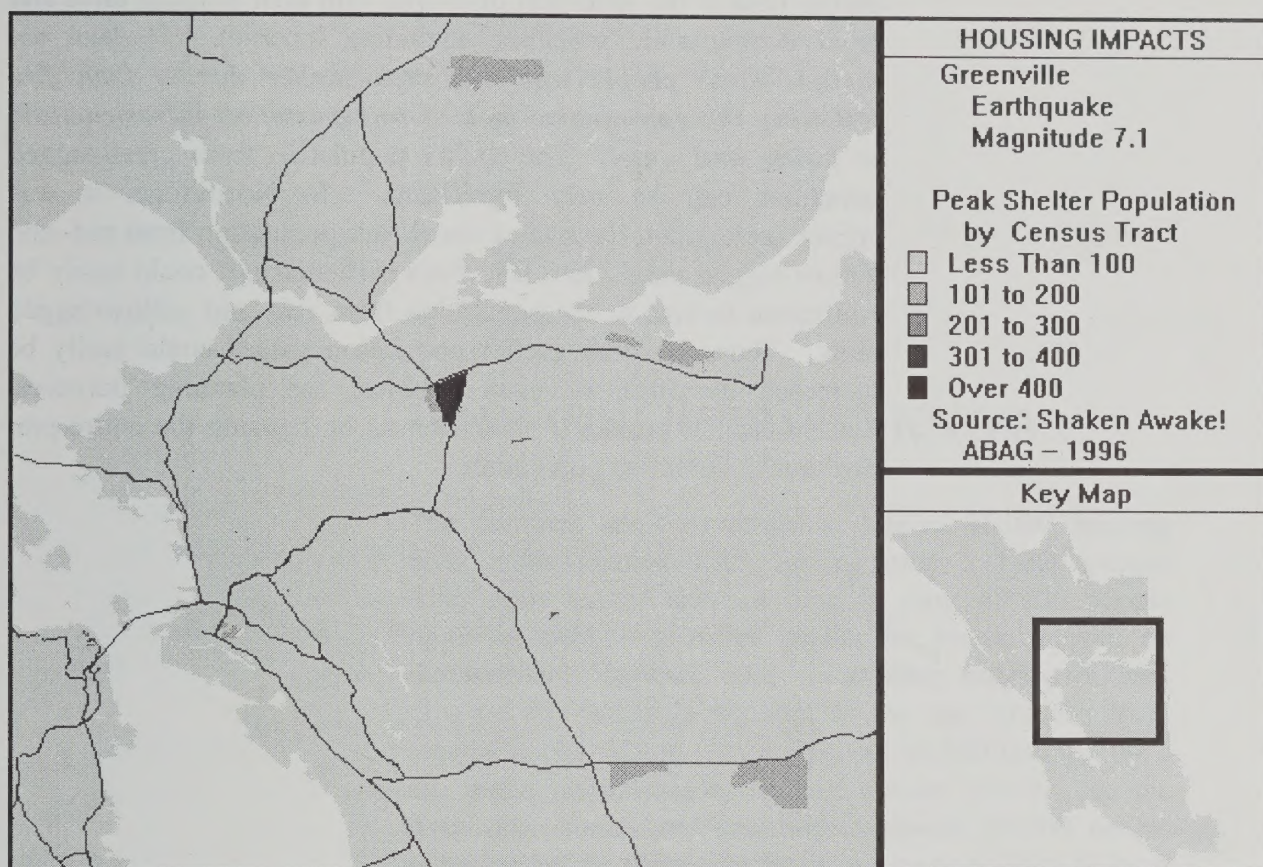
TABLE -- PEOPLE DISPLACED

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Displaced	2312	2901	18	20	846	8	143	490	4	6742
Yellow Tag # People Displaced	3936	1664	48	16	472	34	198	532	9	6909
Total # of People Displaced	6248	4565	66	36	1318	42	341	1022	13	13651

TABLE -- PEAK SHELTER POPULATION

County	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Red Tag # People Sheltered	600	751	3	5	254	0	37	131	0	1781
Yellow Tag # People Sheltered	1054	394	11	4	136	6	46	131	1	1783
Total Shelter Population	1654	1145	14	9	390	6	83	262	1	3564

FIGURE -- PEAK SHELTER POPULATION



Alameda and Contra Costa counties are projected to generate the largest peak shelter populations. These two counties combined will account for over 78% of the total peak shelter population. San Francisco County, which accounts for a high percentage of the total shelter population in most other scenarios, is projected to account for only 11% of the total. Of the eleven scenarios, the Greenville earthquake projected shelter population for San Francisco is the lowest for this city.

However, the shelter pattern between older urban counties and newer suburban counties is repeated here -- while in Alameda County 64% are projected to come from *yellow*-tagged dwelling units, in Contra Costa County 66% are expected to come from *red*-tagged dwelling units. It appears that the older and denser counties generate shelter populations with less severe damage to their buildings.

Care should be taken in using these results. In particular, the peak shelter population is the minimum value for people *requiring* shelter (due to the structural problems with their housing units and other demographic variables, including income). *It does not include those people who will seek shelter due to fear, fire following the earthquake, lack of transportation infrastructure, or power and water.* The shelter population from green-tagged structures can be very significant. In Northridge, it was approximately half the size of the shelter population from red- and yellow-tagged units. In a Bay Area earthquake, it could easily be equivalent in size to the population from red- and yellow-tagged units. Thus, the peak shelter population values could easily be increased by 50%, or even doubled, for planning purposes. Finally, shelter providers should count on housing the entire pre-earthquake homeless population.

WHY YOU NEED TO KNOW

The numbers are overwhelming: almost 88,000 housing units made uninhabitable, forcing over 211,000 people from their homes and resulting in over 63,000 people requiring publicly-provided shelter for an earthquake on the northern Hayward fault. In another earthquake, this time on the peninsula segment of the San Andreas fault, located in San Mateo County, almost 46,000 housing units are made uninhabitable, forcing almost 109,000 people from their homes and resulting in almost 29,000 people requiring public shelter. What is our responsibility as local governments and mass shelter providers? Why do we need to understand how these numbers affect individual cities?

Bay Area totals can be overwhelming. They can also lead to a sense of denial (“Those 211,000 people must be in Oakland or San Francisco; they’re not in *my* city.”) With over 6 million people in our region, less than 4% of the total population is out of their homes even in the Northern Hayward scenario. Yet every city in the region is affected by one or more of these events. We *all* need to know the size of our problem and the reasons for its size, for only by knowing *how many* and *why* can we:

- work to reduce these numbers;
- respond effectively when these earthquakes occur; and
- plan *now* to speed up the recovery process.

LOCAL GOVERNMENT CHECKLIST

Local governments have the power to have a huge impact on the size of this problem by designing and implementing effective mitigation, response and recovery programs now. Examples of city programs are included in a subsequent section. An effective local government program should include the following.

Mitigation

1. Owners of *wood-frame homes* should be encouraged to ensure that these structures are adequately bolted to their foundations and have adequate bracing.
 - ☐ Building departments can have guidelines and sample plans. They can offer incentives to homeowners to encourage this work.
 - ☐ Emergency services personnel, through their neighborhood preparedness programs, can target areas with the largest problems, due to concentrations of these older homes and areas exposed to the highest ground shaking intensities.
 - ☐ Housing and historic preservation agencies can educate owners of historic homes on retrofit options. The next earthquake should not destroy our architectural heritage.
 - ☐ Public affairs departments can include articles on the need to retrofit homes, as well as basic information on how to go about retrofitting these homes, in local government newsletters.
2. Encourage the addition of earthquake bracing to *mobile homes*.
 - ☐ Cities can write to the State Department of Housing and Community Development to encourage the creation of public information packets dealing with the costs and benefits of earthquake bracing.
 - ☐ Emergency services personnel can speak at mobile home parks on the need to add earthquake bracing to these homes.
 - ☐ Public affairs departments can include articles on the need to add earthquake bracing to mobile homes in local government newsletters.

3. Encourage owners of *multi-family housing* to retrofit their buildings to resist earthquake forces.
 - ☐ Building departments should inform owners of unreinforced masonry buildings that they should consider retrofitting these buildings to the highest standard that the owners can afford. Most local codes, including the Uniform Code for Building Conservation (UCBC), are *life safety* standards, not standards designed to allow these buildings to be functional or habitable following a strong earthquake.
 - ☐ Building officials can participate in the development of guidelines for the retrofit of other multi-family housing. Unfortunately, retrofitting these structures is neither simple nor inexpensive.
 - ☐ Emergency services personnel, through their neighborhood preparedness programs, can target the occupants of these buildings with special preparedness materials.
 - ☐ Housing and redevelopment agencies can designate areas of older multi-family housing as part of redevelopment areas to help owners obtain financing for retrofit *before* the earthquake.
 - ☐ Public information departments can speak to groups of businesses and owners about the need to retrofit multi-family buildings.

Response

- ☐ Building departments should have an idea of the number of inspections that they will be performing following an earthquake.
- ☐ Building inspectors should make a particular effort to talk with occupants of green-tagged structures to reassure them of the habitability of these lightly damaged buildings.
- ☐ Emergency services personnel should be aware of the areas in their cities that are subject to the strongest shaking. Some of these areas may also experience ground failure, gas leaks and water pipeline breaks, and are at a higher risk of fire.
- ☐ Local disaster plans should recognize that first responders may need to pay particular attention to multi-story buildings with weak ("soft") first floors (usually due to the presence of parking), for these structures are particularly prone to partial collapse.

- ☐ Public affairs departments should prepare materials to educate residents on the safety of green-tagged buildings. Damage to tile and wallboard does not necessarily mean that the building is unsafe to live in.

Recovery

Non-government organizations, such as the American Red Cross, provide emergency public shelter for several weeks following the disaster. When these shelters close, the local governments are responsible for long-term sheltering and housing recovery.

- ☐ Building departments should have established criteria, perhaps similar to those now being developed by the City of Los Angeles, for the repair of earthquake damaged housing now, before the earthquake.
- ☐ Building departments should be prepared for a wave of questions and permits for the retrofit of undamaged housing.
- ☐ Housing and redevelopment agencies should be familiar with public financing options available for the repair of low-income and senior multi-family housing to minimize the number of units permanently lost and the housing stock recovery time. "Ghost towns" need to be minimized.
- ☐ Single family housing will recover in six months to two years due to the wider insurance coverage and the easier availability of "standard" financing. Emergency shelters are available for several weeks. Recovery can easily take ten years.

MASS CARE PROVIDER CHECKLIST

Response

Non-government organizations, such as the American Red Cross, share the responsibility for providing these shelters in the period following an earthquake. Mass care providers can use the projections of the sheltering model to determine the number, location, and capacity of shelters that will be required to meet the anticipated peak demand. This shelter plan will provide the basis for staffing and training programs to ensure that the shelters can be opened and operated. The projections may serve as the basis for inter-organizational planning and assignment of responsibilities. The numbers provided in this document can assist in pre-planning for that emergency response activity in terms of :

- ☐ logistics
- ☐ supplies
- ☐ staffing

In addition, the number of displaced persons can be used as a basis for planning for demand for food and shelter.

Mitigation

There is also a huge potential for reducing the demand for public shelter through public education and planning. Shelter residents are most likely to come from multi-family housing units and have low incomes. Shelter providers should collaborate with the agencies which provide services to these populations now, before an earthquake.

- ☐ Encourage the development and distribution of earthquake information in the languages of the community.
- ☐ Develop materials now, before the earthquake, on personal preparedness to limit the need for public shelter after the earthquake.

Recovery

Emergency shelter providers need to establish contacts with local government housing departments now to better coordinate and plan for the smooth transition from emergency shelters to medium and long-term sheltering.

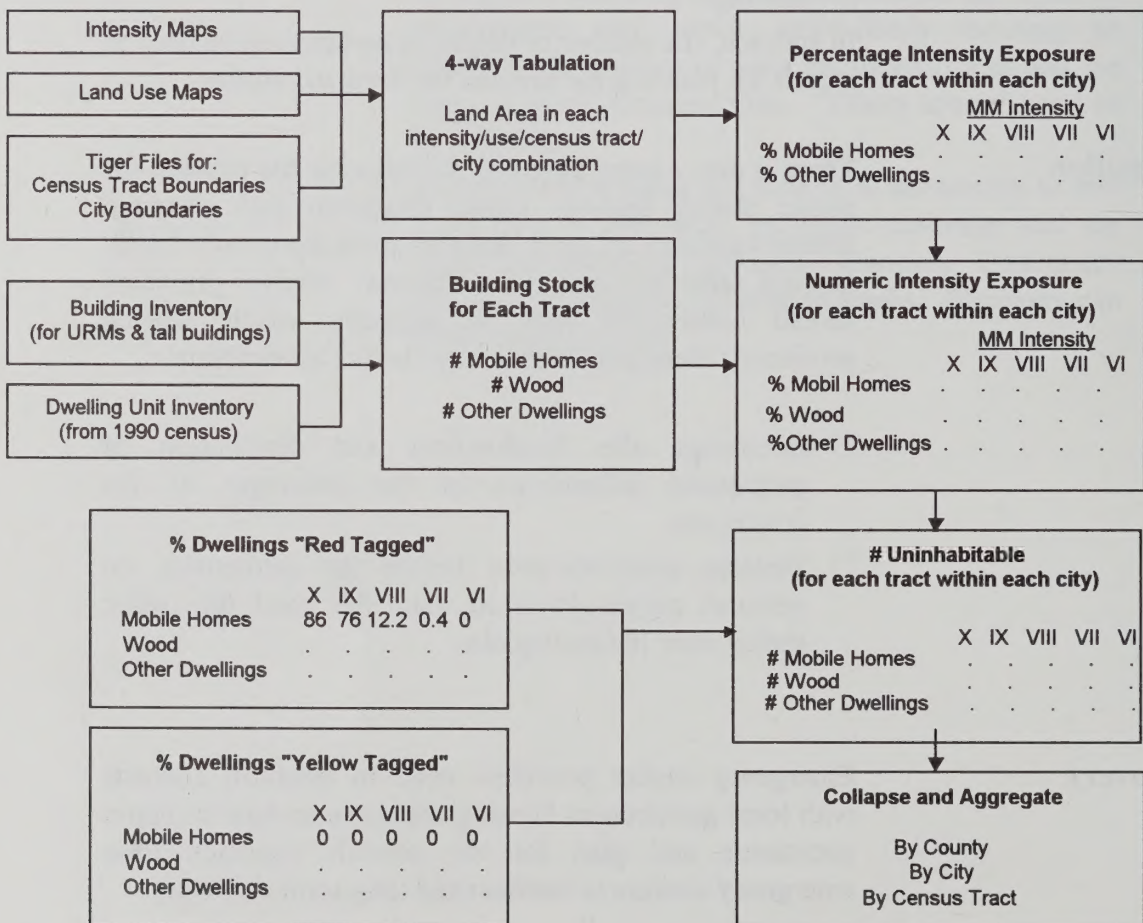
HOW WE DEVELOPED THE NUMBERS

Proper use of the estimates of uninhabitable dwelling units, as well as the estimates of peak shelter population, requires a basic knowledge of the key assumptions made during the modeling effort.

OVERVIEW

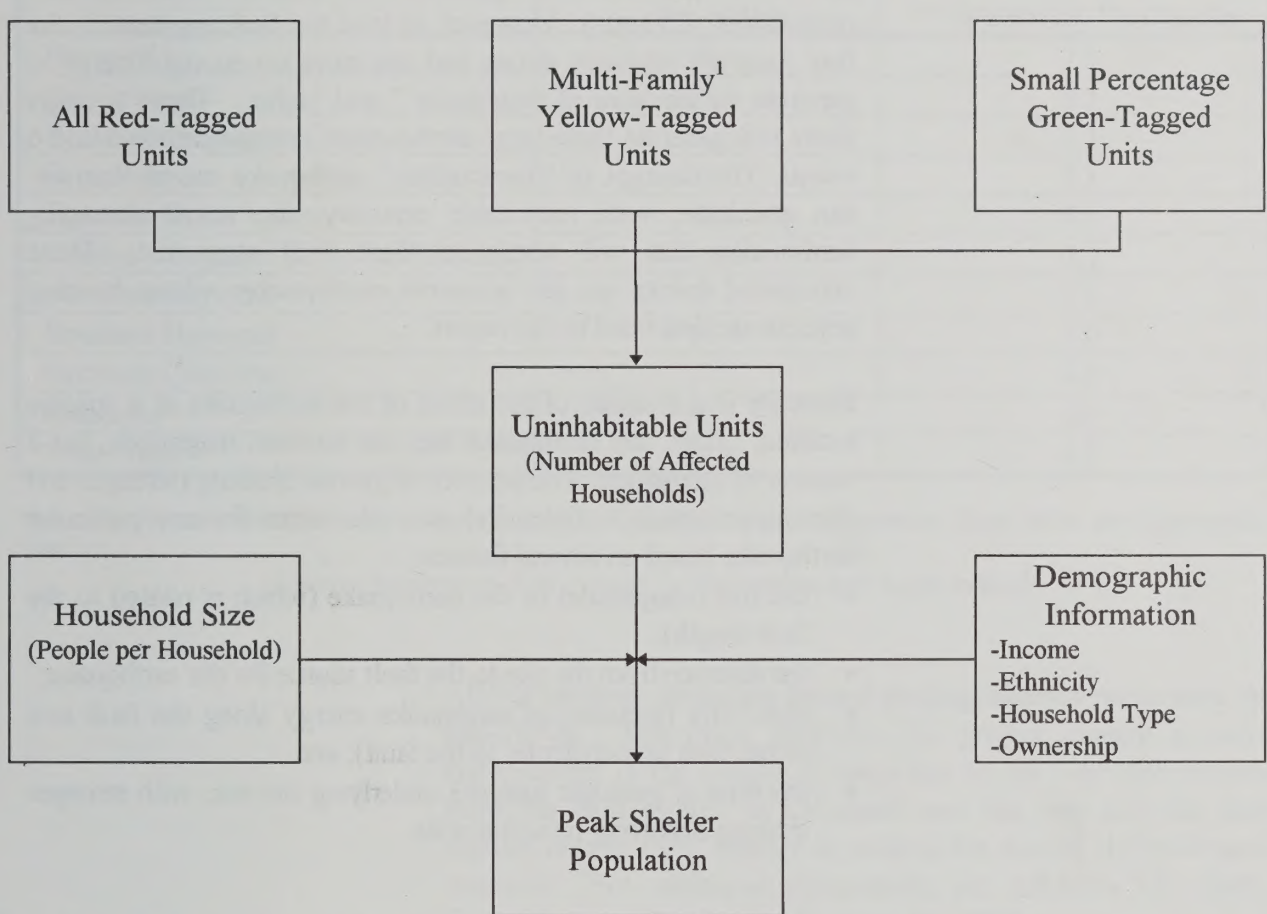
The model used to create these estimates of uninhabitable housing units is summarized in the following diagram. This model contains five major components, each of which relies on a number of simplifying assumptions and is based on imperfect information: (1) intensity mapping; (2) land use mapping; (3) TIGER file maps for census tract and city boundaries from the U.S. Bureau of the Census; (4) residential building stock; and (5) matrices relating intensity exposure and residential construction type to percentages of units made uninhabitable.

FIGURE: MODEL FOR ESTIMATING UNINHABITABLE DWELLING UNITS



The results of this model are used, in turn, to estimate the number of people seeking public shelter, as summarized in the following diagram. This model has two components: (1) demographic information and (2) statistical information relating uninhabitable units and demographic data to peak shelter population.

FIGURE: MODEL FOR ESTIMATING PEAK PUBLIC SHELTER POPULATIONS



Each of these model components, together with their strengths and weaknesses, is described on the following pages.

¹ Single-family yellow-tagged units remain habitable.

INTENSITY MAPPING

Magnitude is a measure of overall earthquake size. Modern seismologists tend to use moment magnitude, rather than Richter (or 'local') magnitude, because it best reflects the energy released by the earthquake.

Fault segments generate "*characteristic*" earthquakes. Some faults are weak and tend to generate earthquakes with moment magnitudes of 5 and 6. However, at least ten fault segments in the Bay Area are relatively strong and can store up enough energy to generate earthquakes of magnitude 7 and higher. These stronger faults will generate these large earthquakes, not magnitude 5 and 6 events. The concept of "characteristic" earthquake means that we can anticipate, with reasonable certainty, the actual damaging earthquakes that will occur on these fault segments. These anticipated events are the *scenario earthquakes* whose housing impacts are described in this report.

Intensity is a measure of the effect of the earthquake at a specific location. Thus, any earthquake has one moment magnitude, but a number of intensities. The severity of ground shaking (strength and damage potential, or *intensity*) at a site varies for any particular earthquake based on several factors:

- the size (magnitude) of the earthquake (which is related to the fault length);
- the distance from the site to the fault source for the earthquake;
- directivity (focusing of earthquake energy along the fault axis rather than perpendicular to the fault); and
- the type of geologic material underlying the site, with stronger shaking occurring on softer soils.

During this project, three maps were produced for past earthquakes for use in testing the models:

- 1906 San Andreas earthquake on the entire Bay Area length of the San Andreas fault;
- 1989 Loma Prieta earthquake on an offshoot of the San Andreas fault in the Santa Cruz Mountains area; and
- 1984 Morgan Hill earthquake on a portion of the southern Calaveras fault.

To look at future earthquakes, an additional eleven intensity maps were produced to correspond to eleven earthquake scenarios based on ten fault segments. (Both segments of the Hayward fault rupturing at once provides the eleventh scenario.)

Moment Magnitude Based on Fault Length for Scenario Earthquakes

Source Fault	Fault Length (in km) (See Note)	Moment Magnitude of Characteristic Earthquake
Hayward	85.0	7.3
San Gregorio	57.1	7.1
Healdsburg-Rodgers Creek	56.5	7.1
Greenville	53.9	7.1
Concord-Green Valley	53.2	7.1
Peninsula Segment of the San Andreas	52.4	7.1
Northern Hayward	49.3	7.1
Southern Hayward	44.7	7.0
Northern Calaveras	37.2	6.9
Maacama	32.3	6.8
West Napa	24.1	6.7

Note : The formula used to estimate moment magnitude for each of these fault segments (from Wells and Coppersmith, 1994) is:

$$\text{Moment Magnitude} = 5.16 + [1.12 \times \log (\text{surface fault length in km})]$$

ABAG has been producing ground shaking intensity maps since the mid-1970s. The maps used for this project present a major improvement in the quality of maps due to the way that distance from the fault rupture is calculated and the way that the fault rupture area is used directly in scaling the size of those distance contours. For additional information, see ABAG's "On Shaky Ground" report (Perkins and Boatwright, 1995).

LAND USE MAPPING

ABAG's geographic information system (BASIS) contains an existing land use map file, last updated in 1993 to reflect 1990 land use. It is based on a multi-leveled categorization scheme first designed by the U.S. Geological Survey. The map file contains the following residential categories:

- 11 General residential (usually less than 1/3 acre lots)
 - 111 1 & under Dwelling Units (DUs) per hectare (2-5 ac. lots)
 - 112 2 - 8 DUs per hectare (approx. 1/3 to 1 acre lots)
 - 113 9 & over DUs per hectare (less than 1/3 acre lots)
 - 114 Mobile home parks (part of 113 but listed separately)

The map file also contains the following residential/commercial mixed use categories:

- 16 General residential/commercial mixed use
 - 161 Residential/commercial mixed use -- mixed use of land areas
 - 162 Residential/commercial mixed use -- mixed use within buildings

Finally, military residential housing is contained in the file under "military" rather than under "residential" or "mixed use."

- 1251 Military residential

The land use file was updated to 1990 using a combination of aerial photography, 1990 census data, and data from ABAG's Local Policy Survey (used in ABAG's population projections program. For a complete list of the data codes in the land use file, as well as a description of the source of the data, see ABAG's land use report (Perkins, 1994).

TIGER FILE MAPPING OF CENSUS TRACT AND CITY BOUNDARIES

The analysis units used in this effort are *1990 census tracts split by city boundaries*. There are *2186 such units* in the Bay Area. Positional inaccuracies in the TIGER/Line files and difficulties in running the analysis for dates other than census years (e.g. ABAG projections only drop to census tract levels), prevented the use of census block groups split by city boundaries. There are 6305 such areas in the Bay Area.

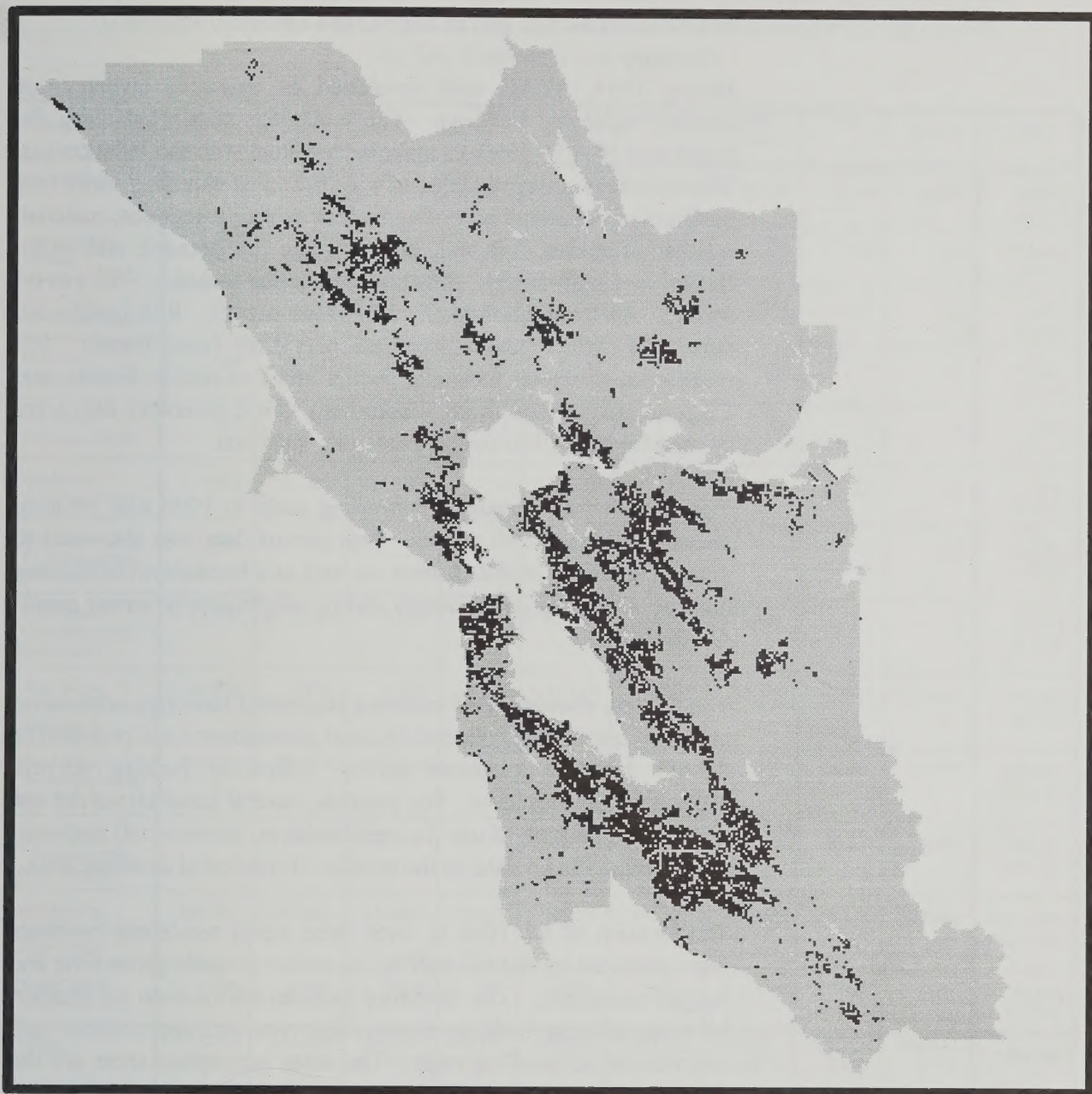


FIGURE -- AREAS OF RESIDENTIAL LAND USE

RESIDENTIAL BUILDING STOCK

During 1994, ABAG staff developed an extensive inventory of existing residential buildings. The work was conducted using the based data of April 1990, to make it consistent with the 1990 census. This inventory groups buildings *by numbers of dwelling units* (not numbers of buildings) according to four sets of categories: material, number of stories (1-3; 4-7; and 7+), age (by decade), and multi-family vs. single family. Material categories include: Wd (wood frame); MH (mobile home); LM (light metal); RM (reinforced masonry); UM (unreinforced masonry); SF (steel frame); RC (reinforced concrete, including ductile and non-ductile frame); and CS (concrete or steel frame - unknown). These inventory data were created for each 1990 census tract - city map unit.

The data on *total number of dwelling units* in 1990 was obtained directly from the 1990 census. That census data was also used to obtain a *count of mobile homes*, as well as a breakdown of housing units by *decade of construction* and by *single-family versus multi-family*.

The data on *unreinforced masonry* residential buildings is based on actual inventory data collected by local governments and provided to ABAG during a telephone survey. Follow-up building surveys cleaned up the local data. For example, several jurisdictions did not collect data on type of use (i.e. residential vs. commercial) and even more did not obtain data on the number of residential dwelling units.

The location of *tall* (that is, over three story) residential buildings were collected by ABAG staff to the extent possible given time and budget constraints. The inventory includes information on location by street address, building construction type and approximate age, and number of dwelling units. The most incomplete areas are the City of Oakland and the City of San Francisco. For these two cities, very few actual buildings are identified by street address.

The results of this process, aggregated to the county level, are provided in the following table.

ABAG's projected 1990-1995 increase in dwellings could be added to a post-1990 category in the future.

TABLE: EXISTING (1990) DWELLING UNITS BY CONSTRUCTION TYPE
(Data for buildings over 3 stories that are not unreinforced masonry are estimated
for San Francisco and Oakland)

Construction Type	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Mobile Homes	6,904	7,412	8,880	3,878	113	3,512	20,926	4,646	11,797	68,068 (2.8 %)
Unreinforced Masonry	4,408	171	147	1	18,921	152	74	56	63	23,993 (1.0 %)
Non-Wood, 4-7 Stories, <1940	730	0	0	0	3,194	60	204	136	0	4,324 (0.2 %)
Non-Wood, 4-7 Stories, >1939	599	107	0	0	2,496	1,064	999	0	77	5,342 (0.2 %)
Non-Wood, 7+ Stories, <1940	436	0	0	0	3,309	0	64	0	0	3,809 (0.1 %)
Non-Wood, 7+ Stories, >1939	4,435	292	281	0	17,289	1,355	1,246	155	412	25,465 (1.0 %)
Wood-Frame, 4-7 Stories, <1940, Multi-Family	748	0	27	0	22,718	155	6	0	0	23,654 (1.0 %)
Wood-Frame, 4-7 Stories, >1939, Multi-Family	18,590	3,509	1,640	0	12,462	13,490	8,143	0	0	57,834 (2.3 %)
Wood-Frame, 1-3 Stories, <1940, Multi-Family	48,008	4,773	6,648	1,291	85,123	7,461	10,204	2,907	2,799	169,214 (6.9 %)
Wood-Frame, 1-3 Stories, >1939, Multi-Family	115,057	68,342	35,924	6,801	51,757	56,451	141,277	24,283	24,772	524,664 (21.3 %)
Wood-Frame, 1-3 Stories, <1940, Single Family	58,929	12,960	20,058	4,077	48,943	17,264	20,190	6,009	14,687	203,117 (8.3 %)
Wood-Frame, 1-3 Stories, >1939, Single Family	240,701	215,812	114,805	27,654	56,173	147,437	330,682	80,418	104,452	1,318,134 (53.6 %)
"Other" (tents, caves, boats, etc.)	5,771	2,767	3,225	493	6,350	3,381	6,216	923	1,998	31,124 (1.3 %)
TOTAL	505,316 20.6 %	316,145 12.8 %	191,635 7.8 %	44,195 1.8 %	328,848 13.4 %	251,782 10.2 %	540,231 22.0 %	119,533 4.9 %	161,057 6.5 %	2,458,742

The 1940 cut-off date is extremely important. For example, foundation bolting of single family wood-frame dwellings was more common after 1940.

For a more detailed description of each of these categories, as well as a short description of common problems in earthquakes, see Appendix A.

MATRICES FOR PREDICTING PERCENT OF UNITS MADE UNINHABITABLE

The final matrices used in this project for relating intensity and building construction to percent of dwelling units made uninhabitable are shown in the tables below, the first for red-tagged units and the second for yellow-tagged multi-family units. Prior to ABAG's work on housing habitability, the only published matrix for relating these variables was developed by Dunne and Sonnenfeld (1991). The matrices developed for *red-tagged* and *yellow-tagged* units in this project has been modified from this earlier matrix based on actual data from the Loma Prieta and Northridge earthquakes. The percentages are provided using two significant figures, with a the smallest unit equal to 0.01%.

TABLE: PERCENT OF DWELLING UNITS RED TAGGED

TYPE	INTENSITY					
	V	VI	VII	VIII	IX	X+
Mobile Homes	0	0	0.87	40	90	100
Unreinforced Masonry	0	0.05	2.9	45	70	80
Non-Wood, 4-7 Stories, <1940	0	0.30	8.0	45	70	80
Non-Wood, 4-7 Stories, >1939	0	0	0	16	54	70
Non-Wood, 7+ Stories, <1940	0	0.30	8.0	45	70	80
Non-Wood, 7+ Stories, >1939	0	0	0	16	54	70
Wood-Frame, 4-7 Stories, <1940, Multi-Family	0	1.4	2.5	45	70	80
Wood-Frame, 4-7 Stories, >1939, Multi-Family	0	0	0.09	10	15	25
Wood-Frame, 1-3 Stories, <1940, Multi-Family	0	0.05	0.53	11	44	64
Wood-Frame, 1-3 Stories, >1939, Multi-Family	0	0.01	0.04	6.5	15	25
Wood-Frame, 1-3 Stories, <1940, Single Family	0.01	0.04	0.12	1.8	8.4	12
Wood-Frame, 1-3 Stories, >1939, Single Family	0	0	0.02	0.18	0.69	1.8
"Other" (tents, caves, boats, etc.)	0	0	0	0	0	0

**TABLE: PERCENT OF DWELLING UNITS YELLOW TAGGED
(SINGLE FAMILY UNITS NOT RENDERED UNINHABITABLE)**

TYPE	INTENSITY					
	V	VI	VII	VIII	IX	X+
Mobile Homes	0	0	0	0	0	0
Unreinforced Masonry	0	3.3	6.2	8.5	30	20
Non-Wood, 4-7 Stories, <1940	0.30	7.7	37	25	30	20
Non-Wood, 4-7 Stories, >1939	0	0	0	38	16	16
Non-Wood, 7+ Stories, <1940	0.30	7.7	37	25	30	20
Non-Wood, 7+ Stories, >1939	0	0	4	38	16	16
Wood-Frame, 4-7 Stories, <1940, Multi-Family	0	1.7	9.7	25	10	10
Wood-Frame, 4-7 Stories, >1939, Multi-Family	0	0.05	2.6	17	25	25
Wood-Frame, 1-3 Stories, <1940, Multi-Family	0	0.15	0.94	6.6	20	20
Wood-Frame, 1-3 Stories, >1939, Multi-Family	0.01	0.02	0.10	12	13	22
Wood-Frame, 1-3 Stories, <1940, Single Family	0	0	0	0	0	0
Wood-Frame, 1-3 Stories, >1939, Single Family	0	0	0	0	0	0
"Other" (tents, caves, boats, etc.)	0	0	0	0	0	0

Small changes to the values in these matrices have a significant impact on estimates of uninhabitable units. In particular, damage to wood-frame dwellings is an extremely significant component of the dwelling losses. For example, the over 32,000 wood-frame dwelling units built after 1939 predicted to be uninhabitable in a southern Hayward scenario is 42% of the total uninhabitable units.

Note that the "0" values provided in these tables are actually greater than zero, but still quite small. Although occasional dwellings are "tagged" in these categories (as can be seen in Appendix B and C), there are also large numbers of dwellings exposed to these relatively low levels of shaking.

² Single family homes remain habitable if yellow-tagged. Yellow-tagging does not occur with mobile homes.

UNINHABITABLE UNITS BASE

Loss of habitability is calculated directly from damage to the residential occupancy inventory, and from assumptions about losses to key infrastructure (including transportation, water and power). All households living in uninhabitable units will seek alternative shelter. Many will stay with friends and relatives or in the family car. Thus, only a portion of those displaced from their homes will seek public shelter, and some will seek shelter even though their residence may have insignificant damage. The data on red- and yellow-tagged structures, together with information on the numbers of untagged or green-tagged structures, in each area becomes the first of three components in calculating shelter populations.

Depending on weather conditions, families living in units affected by loss of water and power may require only feeding and sources of potable water or may be forced to seek alternative shelter. A cold-weather event will also trigger a higher percentage of those who would normally use cars and tents as alternative shelters needing to use public shelters. However, no statistics on cold-weather disasters in this country are available. The weather following major hurricanes, as well as both the Loma Prieta and Northridge earthquakes, has been reasonable.

It is important to note that *these estimates do not account for any significant numbers of people being displaced by secondary disasters, such as post-earthquake fire, dam failure inundation, or major hazardous materials release*. California has major programs to minimize the threat of dam failure and hazmat problems. Attempting to anticipate the location and magnitude of dam failure or hazmat releases is well beyond the scope of this project. On the other hand, one could assume that small fires will, in fact, be associated with future earthquakes. However, due to the relatively low densities in population, such fires should be able to be contained. The fire suppression systems in both Oakland and San Francisco have been greatly improved in the last few years as a result of the Oakland fire and the Loma Prieta earthquake disasters. Additional persons seeking shelter due to small secondary fires can be assumed to be consistent with the numbers affected by transportation, water and power losses. Further research in this area may be warranted.

DEMOGRAPHIC DATA USED IN PEAK SHELTER POPULATION MODELING

The U.S. Bureau of the Census provides essential information on the demographic factors that are used in the shelter population model: income, ethnicity and housing type. These data are available by census tracts split by city boundaries. Thus, the same geographic areas used for assessing the impact of earthquakes on existing structures is used for the shelter population modeling. Categories of family income used in the shelter model concentrate on the lowest income groups: less than \$10,000, to \$15,000, to \$25,000, and to \$35,000. All families with incomes of over \$35,000 were grouped together. Ethnicity data is used to categorize households as White-non Hispanic, African American, Hispanic, and other (Asian and Native American). Two types of housing distinctions are made in the modeling: the single family vs. multi-family and own vs. rent.

PREDICTING SHELTER POPULATIONS BASED ON DAMAGE TO DWELLINGS AND DEMOGRAPHIC DATA

The structure of shelter population model was based on a review of historical case files for earthquakes, hurricanes and other types of disasters. These records show that people of different socio-economic backgrounds differ in their decisions to seek public shelter after a disaster. The resulting sheltering model is a multi-attribute model (sometimes called a weight and rate model) based on damage and on three major demographic factors that predict the likelihood of seeking public shelter: family income, ethnicity, and housing type. The model weights the relative importance of these three factors for uninhabitable (red tagged) dwellings, and for severely damaged (yellow tagged) dwellings. Each demographic factor is subdivided into a set of discrete categories: five levels of family income, four ethnic groups, and two housing types. A rating is assigned to each category representing the probability that a family meeting the damage and socioeconomic criteria will seek shelter. The relative importance weights of the demographic factors and the probability ratings of the categories were determined from three sources: interviews and surveys of shelter workers conducted for the 1992 ABAG/GWU project; a survey of earthquake victims following the Northridge Earthquake; interviews, surveys, and a workshop conducted with Red Cross shelter experts after the Northridge

earthquake. Findings from these three independent investigations were consistent. The importance weights are shown in the following table, while the probability ratings are shown in the second table. Family income level is the most important factor in the prediction of the likelihood of seeking public shelter. Families with incomes of less than \$10,000 are 6 times more likely to seek shelter if their homes are red tagged and ten times more likely to seek shelter if their homes are yellow tagged than are families with incomes of over \$35,000. The income effect is even more pronounced if the low income population is minority. Housing type becomes a more important factor as the damage level decreases (the choice to leave is voluntary) with renters more likely to seek shelter than are owners.

TABLE: IMPORTANCE OF DEMOGRAPHIC FACTORS IN PREDICTING SHELTER POPULATIONS

Demographic Factor	Weighting Factor for Red-Tagged Dwellings	Weighting Factor for Yellow-Tagged Dwellings
Income Factor	0.60	0.50
Ethnicity Factor	0.25	0.25
Housing Type	0.15	0.25

These weights, when multiplied by rating factors in the table on the facing page, provide the percentages of those seeking public shelter.

Note that data for Native Americans is extremely scarce. Some information from Alaskan disasters indicates that the factor for those seeking shelter is similar to that for whites or Asians.

Additional information on the statistical procedures used to obtain these values are provided in Appendix E.

Two important conclusions can be made from sheltering data collected after the Loma Prieta and Northridge earthquakes. First, shelter populations peak 3-7 days after the earthquake. Two reasons for this observed behavior are:

- 1) after shocks induce residents to leave damaged structures; and
- 2) the inspection and tagging of structures (particularly multi-family buildings) displaces large numbers of low income families.

The figure below shows how the shelter population varied over time following the Northridge earthquake. Note that the shelter population peaked one week after the earthquake.

**TABLE: CONDITIONAL PROBABILITY RATINGS FOR
DEMOGRAPHIC CATEGORIES**

Demographic Factor	Rating Factor for Red-Tagged Dwellings	Rating Factor for Yellow-Tagged Dwellings
Income Level		
< \$10,000	0.60	0.50
\$10,000 - \$14,999	0.30	0.40
\$15,000 - \$24,999	0.20	0.20
\$25,000 - \$34,999	0.10	0.10
>\$35,000	0.10	0.05
Ethnic Group		
White	0.25	0.20
African American	0.50	0.40
Hispanic	0.50	0.40
Asian	0.15	0.15
Native American	0.15	0.15
Housing Type		
Own	0.30	0.20
Rent	0.60	0.50

A second phenomena that is characteristic of earthquakes is that a significant portion of the shelter population requires long-term sheltering (that is, more than three weeks). Many people with homes that are no longer habitable do not have the economic resources to find alternative housing or the social network to provide support. Note in the figure on the following page that shelter population after 14 days was approximately 25% of the peak population; after three weeks the population was approximately 15% of the peak population. Mass care providers, therefore, must have pre-planned how to transition the support of this population to non-emergency care givers.

Three important influences on shelter population were not considered in the modeling process:

- 1) pre-disaster homeless populations;
- 2) secondary disasters; and
- 3) non-resident populations.

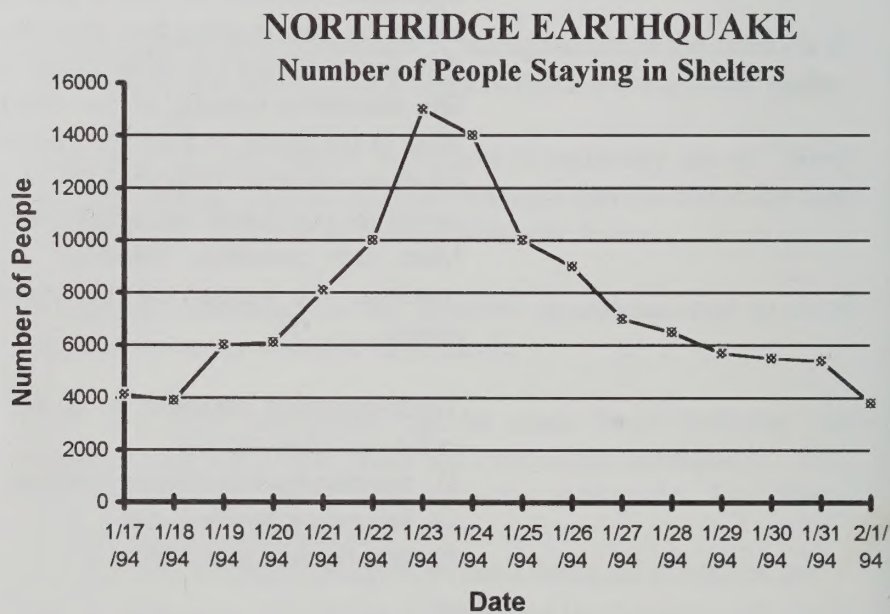
The projections developed for the scenario earthquakes do not include the impact of the pre-disaster homeless on the shelter populations. Experience in urban areas (San Francisco and Oakland after Loma Prieta and Los Angeles after Northridge) has shown that

this impact can be significant. In the short term, the earthquake may disrupt the usual sources of food and shelter for the majority of the pre-disaster homeless. These persons become part of the population that must rely on disaster shelter and feeding provided by disaster relief organizations. Their impact on the estimates for urban areas is two fold:

- they increase the anticipated peak shelter populations; and
- they make up a significant proportion of the population requiring long-term assistance.

The estimates do not consider the impact of a secondary disaster. Fires, inundation from dam breaks, and toxic gas releases can also make areas uninhabitable and will result in increased shelter populations. The sheltering model could be used to predict these populations based on appropriate secondary disaster damage scenarios.

Non-resident populations in an urban area consist of two major groups: commuters and tourists. The commuter population is dependent upon the time of day: Northridge occurred while most people were at home; Loma Prieta occurred when many were on the road during the evening rush hour. Tourist populations are a significant concern in San Francisco.



THE ISSUE OF ACCURACY -- TESTING THE MODELS BY COMPARING ACTUAL VERSUS PREDICTED VALUES

UNCERTAINTY

A modeling process can only produce a reasonable approximation of reality. The test of a model is whether or not it produces useful information. The estimates of uninhabitable units, displaced populations and shelter populations are calculated using variables that are also estimates. The uncertainty in the calculations is compounded at each step.

- 1) Given an earthquake, it is uncertain whether or not it will occur on one of the scenario fault sources.
- 2) Given an earthquake on one of the scenario fault sources, the intensity at any given location is uncertain.
- 3) Given an intensity at a particular location, the type of buildings present is uncertain.
- 4) Given the intensity and building stock, the response of the buildings affected and resulting habitability is uncertain.
- 5) Given the damage to a structure, the number of people affected is uncertain.
- 6) Given the number of people affected, their behavior is uncertain.

The models presented in this study are an attempt to provide reasonable estimates of damaged dwelling units, displaced persons, and peak shelter populations. No attempt has been made, however, to calculate the statistical uncertainty in these estimates. Rather, each step in the model has been tested to ensure that the estimates are as accurate as possible in predicting past damage, while acknowledging that some errors should remain because of our belief that some aspects of future earthquakes will be different than past earthquakes.

TESTING THE INTENSITY MODEL

The key test for any mapping scheme which proposes to predict the intensity patterns of future earthquakes is its ability to accurately "model" intensity patterns in past earthquakes. In the case of these maps, the principal comparison was made not with the modified Mercalli intensity map published for the Loma Prieta earthquake (Stover et al., 1990), but with actual housing damage patterns from that earthquake as measured by red-tagged dwelling units of

various construction types. These units are in buildings which were "red-tagged" as being unsafe to occupy using a set of criteria published by the California Office of Emergency Services and used fairly uniformly by all of the city and county building inspection departments.

The testing process involved a comparison of predicted red-tagged units to actual red-tagged units. First, alternative models to predict intensity patterns in the Loma Prieta earthquake were generated. A second model was then run for each resulting intensity map to predict the number of red-tagged units. This second model used estimates of the existing land use, the housing stock, and the damage matrices that relate the percent of red-tagged units by construction type to the intensity. These predictions were then systematically compared with the actual red-tagged unit counts for the Loma Prieta earthquake for twelve building types, for each of the cities and counties in the region.

To obtain information on the actual red-tagged residential structures in the Loma Prieta earthquake, ABAG designed and conducted a telephone survey of all local government building departments. In particular, we were seeking information on:

- 1) the number of buildings with residential units that were red-tagged;
- 2) data on the number of housing units in each of these buildings;
- 3) data on the location of each of these buildings (preferably by street address);
- 4) data on the type of construction of these buildings (including number of stories, construction material (wood frame, mobile home, unreinforced masonry, other), year or decade built, and presence of parking on the ground floor; and
- 5) number of dwelling units where buildings were subsequently demolished, and those repaired after defined time periods.

Additional information on this survey is contained in Appendix C.

This testing process was a reiterative exercise; actual red-tagged units were compared with revised predictions for the number of those units based on increasingly sophisticated assumptions about the role of directivity and the additional complication of the propagation effect associated with the Mohorovicic discontinuity (the boundary between the crust and the mantle), as well as on improved data on existing land use and building construction/unit counts for the time of the Loma Prieta earthquake. A total of over seventy models were run for this earthquake.

The model with the "best" fit was used to create a revised matrix relating intensity percent red-tagged by modified Mercalli intensity by construction type based on the actual damage data from the Loma Prieta earthquake to predict red-tagged units. This "modified" matrix was then used to estimate the red-tagged units again, reducing the errors even further. However, the changes in the matrix were conservative, reflecting our respect for the quality of the data from earlier earthquakes that went into the original matrix. Finally, a yellow-tagged damage matrix was developed for multi-family dwelling units.

Next, data on red- and yellow-tagged units was collected for the Northridge earthquake. These data were used to again modify the red- and yellow-tagged matrices. In some cases, the addition of these data necessitated changes in the red-tagged matrices that caused the values to be less accurate than those created without the Northridge data. Two examples are for mobile homes and post-1939 wood-frame multi-family construction. The data from Northridge is particularly compelling, however, for these types of construction when exposed to high intensities. Further information on the development of these matrices is contained in Appendix D.

As can be seen in the following table, the "final" predicted number of uninhabitable dwelling units in the Loma Prieta earthquake is reasonably close to the actual number of uninhabitable units.

County	Actual Number of Uninhabitable Units	Predicted Number of Uninhabitable Units
Alameda	3284	1968
Contra Costa	0	159
Marin	2	297
Napa	0	0
San Francisco	9202	11781
San Mateo	76	223
Santa Clara	408	1239
Solano	0	2
Sonoma	0	3
TOTAL	12972	15673

A similar comparison of the results by building type also show that the results are reasonably accurate.

Construction Type	Actual Number of Uninhabitable Units	Predicted Number of Uninhabitable Units
Mobile Homes	101	232
Unreinforced Masonry	1936	2159
Concrete, Steel and Reinforced Masonry 4-7 Stories, < 1940	1981	1778
Concrete, Steel and Reinforced Masonry 4-7 Stories, > 1939	0	158
Concrete, Steel and Reinforced Masonry 7+ Stories, < 1940	1230	1491
Concrete, Steel and Reinforced Masonry 7+ Stories, > 1939	664	1822
Wood-Frame, 4-7 Stories, < 1940	3783	2819
Wood-Frame, 4-7 Stories, > 1939	667	1108
Wood-Frame, 1-3 Story, < 1940 Multi-Family	2018	2278
Wood-Frame, 1-3 Story, > 1939 Multi-Family	216	1583
Wood-Frame, 1-3 Story, < 1940 Single Family	301	161
Wood-Frame, 1-3 Story, > 1939 Single Family	75	84
TOTAL	12972	15673

The largest discrepancies in the tables are for unreinforced masonry and non-wood pre-1940 buildings in San Francisco and Oakland. The wood-frame units are extremely close. These discrepancies are of less concern because the units in these buildings tend to be large. For example, the average number of units in a red-tagged unreinforced masonry building was 29. Thus, the overestimation of red-tagged URM buildings in San Francisco is only about 43 buildings.

The revised model was then tested for a much smaller earthquake, the Morgan Hill earthquake of 1984. This $M = 6.4$ earthquake is at the lower end of the magnitude scale of the scenario earthquakes to

be modeled. The revised intensity model predicted a total of 202 red-tagged units, larger than the 39 units that were actually red-tagged, but much smaller than the 1089 red-tagged units predicted by the original model.

The exercise of fitting the damage associated with the 1906 San Francisco earthquake, the 1989 Loma Prieta earthquake and the 1984 Morgan Hill earthquake clearly indicates that the intensity models developed in the mid-1970s that ABAG has been using, with minor modifications, for almost twenty years have been improved by including directivity. In particular, the fit to the 1989 Loma Prieta damage provides a critical test of these intensity models, improving our ability to predict intensities for areas lying off the ends of the fault sources for these large scenario earthquakes.

An additional improvement is the magnitude scaling derived from the physical model of the source. This scaling allows intensities to remain high near the fault, while falling off more abruptly perpendicular to the fault as the magnitude decreases. The steepness of this fall-off is less pronounced along the fault strike. These effects are significant for the range of magnitudes associated with expected future damaging earthquakes in the Bay Area.

TESTING THE SHELTER PREDICTION MODEL

The Loma Prieta Earthquake is the only recent Bay Area earthquake for which damage and sheltering information is available. The Loma Prieta earthquake produced lower shelter populations that the model predicts. The relatively short duration of the Loma Prieta earthquake produced relatively little infrastructure damage--electricity and water were restored rapidly and most major highways remained open. These factors could lead to a lower number of people seeking shelter from damage, as well as to an increased mobility that would allow people from uninhabitable dwellings to seek alternative shelter. The failure of the model to match the Loma Prieta experience is, therefore, not seen as a severe shortcoming. The geographic pattern of sheltering demand does, however, match that experienced during Loma Prieta.

COUNTY	Actual Peak Shelter Population³	Peak Shelter Population Predicted from ABAG Damage Model⁴	Peak Shelter Population Predicted from Actual Damage⁴
Alameda	772	1,409	2,532
Contra Costa	0	116	0
Marin	0	189	0
Napa	0	0	0
San Francisco	1,650	7,865	5,233
San Mateo	679	130	56
Santa Clara	164	807	275
Solano	0	1	0
Sonoma	0	0	0
TOTAL	3,265	10,517	8,096

³ From American Red Cross Shelter Records

⁴ From GWU Sheltering Model

WHAT IS NEEDED -- OUR NEXT STEPS

Reducing housing losses can spread the resources of shelter providers, lowering costs borne by local, state, and federal governments.

Homeowners, businesses and local governments can all begin to work NOW to make these numbers smaller.

Some ideas include:

- ☐ re-examining the issue of unreinforced masonry housing
- ☐ developing standards for construction and retrofit of wood multi-family housing
- ☐ financing of retrofits and new urban low-income housing
- ☐ public education
- ☐ the emergency inspection process

Several communities in the Bay Area have developed programs which are designed to lessen the effects of housing losses. ABAG has presented awards to six Bay Area cities for these types of programs. These award-winning programs of the cities of Berkeley, San Leandro, Sunnyvale, Albany, Foster City and San Jose are described on the following pages. The impressive part about these programs is that they do more than focus on residents trying to pick up the pieces -- they focus on trying to have fewer pieces to pick up.

CITY OF BERKELEY

1995 POPULATION: 105,855
1995 HOUSING UNITS: 45,912
 Single Family Units: 19,420 (42.3%)
 Multi-Family Units: 26,492 (57.7%)
Key Contact: Arrieta Chakos
City Manager's Office
Phone (510) 644-6580



Although emergency response is critical in assisting people, mitigation of structural problems with homes can prevent the need for emergency response. This mitigation is the goal of Berkeley's Seismic Retrofitting Incentive Program.

This incentive program is a joint effort under the departments of Planning, Housing, and Finance. It provides two economic incentives to homeowners. First, a local ordinance waves permit fees paid to the City for seismic retrofits of non-strengthened residences and unreinforced masonry structures. Since 1992, over 2,000 projects representing \$229,000 in permit fees have been approved without fee payment. This incentive has helped low-income homeowners, and may have increased the degree to which middle- and upper-income homeowners have retrofitted.

Second, the City has a 1.5% tax levied on property transfer transactions; up to one-third of this amount can be applied for seismic upgrades during the sale of property. Qualifying upgrades include foundation repair or replacement, mudsill repair or replacement, wall bracing in basements, foundation-to-mudsill bolting, shear wall installation, water heater anchoring, and securing of chimneys. In two fiscal years, this program has resulted in the completion of 1,300 retrofit projects totaling \$900,000. (This amount also represents lost revenue for the City.)

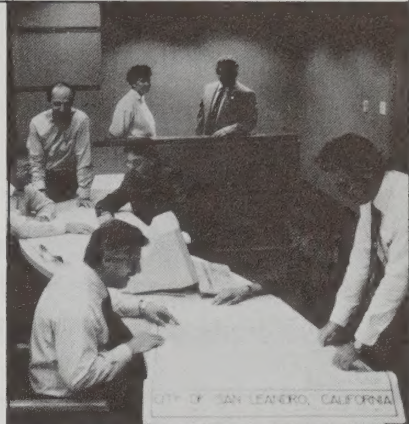
The Seismic Retrofitting Incentive Program is part of a series of efforts undertaken by the City of Berkeley since the Loma Prieta earthquake to address disaster preparedness and mitigation of potential hazards. These activities include establishment of a municipal Office of Emergency Services, setting up of a Citizen's Emergency Response Training program, development of a set of comprehensive standards on mitigation policy and public building design (with the help of seismic safety experts from the University of California), development of a residential seismic retrofit incentive program based on these standards, and passage of two seismic safety bond measures for upgrades of public buildings and infrastructure by City voters. The emergency response training, administered by the City's OES, is one of the keys for reducing shelter needs following an earthquake or other disaster, and is targeted for both staff and citizens. Over 14,000 community members and staff now have had emergency preparedness training.

CITY OF SAN LEANDRO

1995 POPULATION: 72,307
1995 HOUSING UNITS: 30,309
Single Family Units: 18,630 (61.5%)
Multi-Family Units: 11,679 (38.5%)

Key Contacts:

Development Services - Rosie Rios (510) 577-6007
Building Inspection - William Schlock (510) 577-3422 or
Doug Simms -3425



San Leandro's award-winning Home Earthquake Retrofit Program is a program that truly exemplifies taking "THE EXTRA STEP." A large amount of the housing stock in San Leandro is older, wood-framed dwellings, and the same type of construction is expected to be a significant portion of uninhabitable dwellings after an earthquake. Thus, the City developed a technical assistance program as a City-wide service encouraging homeowners to retrofit their homes. Specifically, the Home Earthquake Strengthening Program contains four basic elements: a set of publications to assist the homeowner in getting underway with a retrofit, a separate inspection and permit for this type of project, a tool-lending "library" for those residents doing the work themselves, and community training for retrofit construction.

The Homeowner's Handbook was developed to show how to strengthen wood-framed houses for earthquakes, and was delivered to all single-family residents in the City. A more detailed publication, the Prescriptive Standard and Plan Set, was prepared as a set of numbered construction details for strengthening wood-framed houses and offers a standard scope of work for contractor bids as well. Information specified by the homeowner on the Plan Set makes it easy for the City to process applications for retrofit work and issue permits. The Set, as well as the Program, is available for homeowners at no cost.

The City offers a pre-construction inspection specifically for the earthquake retrofit work to assure that the job will be complete and cost-effective. Permit fees are set at low rates to minimize the number of households avoiding the work because of cost.

A tool lending "library" was established to allow homeowners with "do-it-yourself" initiative to borrow the necessary equipment (under the prescribed standard) for retrofitting at no charge.

A series of five 2-hour construction workshops is offered by the city to those homeowners who want to do bolting and bracing on their own. Taught by both industry experts and City staff, the Seismic Strengthening of Wood Frame Houses series is offered quarterly at a nominal charge. It also covers non-construction earthquake safety measures. A one-day course, Contractor Seismic Safety Training, is required for contractors who wish to be included on the list of qualified contractors available to homeowners in the city.

CITY OF SUNNYVALE

1995 POPULATION: 125,959
1995 HOUSING UNITS: 52,856
 Single Family Units: 25,093 (47.5%)
 Multi-Family Units: 27,763 (52.5%)
Key Contact: Raelene Wong
Emergency Preparedness Coordinator
Phone: (408) 730-7117



Sunnyvale's SNAP program (for Sunnyvale Neighborhoods Actively Prepare) was the first comprehensive program to work with people in neighborhoods to ensure that they were better able to cope with the aftermath of earthquakes. This innovative program serves as the model for other preparedness programs statewide.

SNAP is a cooperative effort between the City government and its citizens. This innovative volunteer emergency preparedness program was developed on a neighborhood-by-neighborhood basis. Now seven years old, the program has exceeded its initial goals and helped foster greater cohesiveness in some neighborhoods.

SNAP provides community self-reliance through a system of training and communications. Five different workshops and a full set of informational materials make up the training program: Basic Committee Training, Topic Training, Captain Training, First Aid/CPR Training, and Advanced Urban Search and Rescue Training.

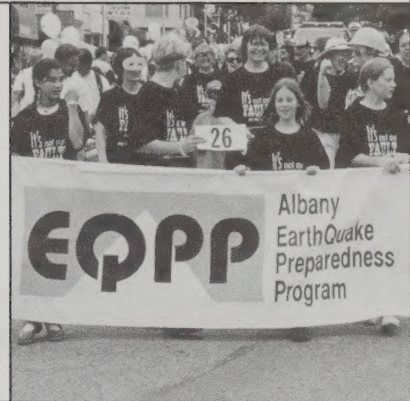
Intra-neighborhood communication is based on a captain and six disaster task committees in each neighborhood group. Neighborhoods are self-defined, with an approximate size of 35-50 homes. Committees are structured to reflect key concerns in the event of a disaster: Communications, Damage Assessment, First Aid, Safety and Security, Search and Rescue, and Sheltering and Special Needs. The captain coordinates these committees, which are based on action, using citizens as resources in time of need. A City-wide steering committee for SNAP is composed of captains who work directly with City staff.

Thus, while training provides education and information, the committees are an active expression of joint government-citizen response. Citizens become part of the decision-making process as well as participate in community improvement.

This program is funded by local tax dollars, and 22% of the City's households participate in it. A total of 265 groups, 400 captains, and 4,500 committee members make up the program thus far. FEMA is using SNAP as a model for residential emergency preparedness.

CITY OF ALBANY

1995 POPULATION: 17,311
1995 HOUSING UNITS: 7,482
 Single Family Units: 3,813 (51.0%)
 Multi-Family Units: 3,669 (49.0%)
Key Contact: Doug Donaldson
Volunteer Neighborhood Captain
Phone (510) 524-4835



Albany's EQPP is its EarthQuake Preparedness Program. Although it was not the first neighborhood and volunteer-based program, its results have been amazing. Over 60% of the City's households, and 70% of the neighborhoods, have participated in one or more parts of this Program.

EQPP is a collaboration of institutional support and zeal of community members. Its two components are training and education offered by the City, and coordination and organization of neighborhood blocks by volunteers.

The training and education program, overseen by the City fire department, is a set of eight classes on disaster preparedness and emergency response. These courses include: Individual and Family Earthquake Preparedness; How to Organize Your Neighborhood; First Aid and Disaster Triage; Cardio-Pulmonary Resuscitation (CPR); Urban Search and Rescue; Fire Safety and Suppression; Emergency Communications; and Foundation Bolting and Shearwall Installation. In addition to the educational role it plays, the Fire Department provides two free services to local residents: earthquake strapping of water heaters, and installation of (paid for) smoke detectors.

Good local earthquake preparedness programs recognize the limitations of direct governmental activity and response. Thus, EQPP has a built-in network of volunteer support. Over 140 neighborhoods ("blocks") have organized within the Program's coordinating structure. Dedicated volunteers provide the grass-roots labor for this program, and these citizens are directed by block captains, who are in turn overseen by six sector coordinators, a steering committee, and the co-chairs of the Program.

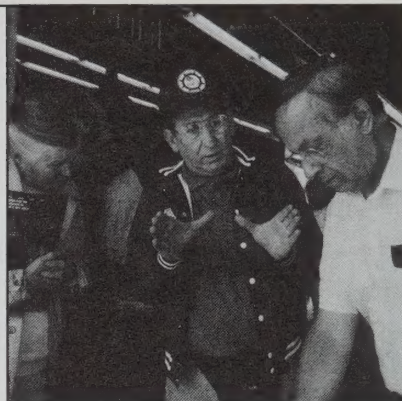
EQPP has helped implement several activities. A City-wide earthquake drill was held in the spring of 1995, involving over 70% of the organized neighborhoods. The drill offered either a full-functional exercise of establishing a command post and response activities, or table-top scenarios gathering residents for discussion of roles and actions.

In addition, preparation at the individual household level is being encouraged through a block matrix project. Block captains are surveying households of their neighborhood on fifteen types of structural and training-based preparedness activities both to motivate residents and measure their response to earthquake readiness.

The City also continues to support these activities through ongoing meetings for sector coordinators and block captains, sponsoring information booths at local events, and recruiting other neighborhoods to participate in this Program.

CITY OF FOSTER CITY

1995 POPULATION: 29,503
1995 HOUSING UNITS: 11,874
 Single Family Units: 4,773 (40.2%)
 Multi-Family Units: 7,101 (59.8%)
Key Contact: Roger Chinn
Lions Club and former City Councilmember
Phone (415) 468-0787 (work)



Foster City's preparedness program is innovative because it is a joint effort with the Foster City Lions Club, with support from the San Mateo County Office of Emergency Services. It is based on active and hands-on community service.

First, homeowners are being encouraged to purchase, install and maintain key items such as fire extinguishers, wrenches for shutting off gas, first aid kits with flashlights, smoke detectors, non-perishable foods, water heater strapping supplies and wall attachments for tall furniture.

Second, do-it-yourself instructions are being developed and several programs and community faires are being held. Instructions focus on:

- ◆ using fire extinguishers;
- ◆ locating and turning off gas and water meters;
- ◆ training for first aid and CPR;
- ◆ strapping water heaters;
- ◆ attaching furniture to walls; and
- ◆ developing escape plans and safety instructions.

Third, a home retrofitting program has been developed to describe structural repairs that can be done on a home, including:

- ◆ foundation repairs;
- ◆ anchoring walls to foundations;
- ◆ wall sheathing; and
- ◆ framing support of garage openings.

Lions Club members are providing labor assistance for this work as necessary, helping the elderly and unemployed with earthquake safety, conducting neighborhood programs, and compiling statistics to continue to motivate residents.

Funding for program expansion is being pursued, using the local Lions Club and wider Lions Club resources, soliciting grants from insurance companies based on life and property risk reduction, and soliciting grants from other parties such as utility companies, foundations, and retail outlets.

CITY OF SAN JOSE

1995 POPULATION: 845,991
1995 HOUSING UNITS: 270,080
 Single Family Units: 165,840 (61.4%)
 Multi-Family Units: 104,240 (38.6%)
Key Contact: Frannie Winslow or John Lane
San Jose Office of Emergency Services
Phone: (408) 277-4595



Source: Degenkolb Associates

The City of San Jose's Residential Seismic Safety Program is remarkable because San Jose is the first city to make a special effort to attack a particularly thorny issue--that of multi-family housing. The City's effort to prepare these residents, and encourage retrofitting apartments over garages that tend to collapse during earthquakes, is ambitious and particularly notable.

Because apartment buildings with "soft" first floors are prone to significant earthquake damage, the City's Office of Emergency Services has evaluated the community's residential building stock and determined both which building types are vulnerable and what appropriate retrofit actions can be done. This information, including building age, configuration, and structural data will be used with geographic risk data provided by ABAG's "On SHAKY Ground" maps to determine priorities for upgrading the multi-unit buildings. Small-scale structural reinforcing of the highest risk buildings could result in substantial savings in damage, potential neighborhood blight, and homelessness.

This program was started with a grant from the City's Community Development Block Grant Program. The complete program has two parts: outreach and safety. Outreach efforts will center on the hiring of a consulting structural engineer to review retrofit recommendations. These recommendations will be coordinated with the Building Division of Planning, as well as the Housing Department, to make sure they conform to all requirements and procedures. Some technical assistance will be available through workshops. Future efforts will be guided by follow-up surveys and the tracking of contracts.

Although legal, political, technical, and economic questions remain, this new program has the potential to be very effective.

REFERENCES

- Applied Technology Council (ATC), 1985. *ATC-13 – Earthquake Damage Evaluation Data for California*. ATC-13: Redwood City, CA, 492 pp.
- Applied Technology Council (ATC), 1991. *Procedures for Postearthquake Safety Evaluation of Buildings (ATC-20)*. State of California Governor's Office of Emergency Services: Sacramento, CA, 144 pp.
- Boore, D.M., Joyner, W.B., and Fumal, T.E., 1993. *Estimation of Response Spectra and Peak Accelerations from Western North American Earthquakes: An Interim Report*. U.S. Geological Survey Open-File Report 93-509, Denver, CO.
- Borcherdt, R.D., Gibbs, J.F., and Lajoie, K.R., 1975. *Map Showing Maximum Earthquake Intensity Predicted in the Southern San Francisco Bay Region, Calif., for Large Earthquakes on the San Andreas and Hayward Faults*. USGS Map MF-709, scale 1:125,000.
- Cuny, F.C., 1975. *Strategies and Approaches for the Provision of Emergency Shelter and Post-Disaster Housing*. Intertect: Dallas, Texas.
- Dunne, R.G., and Sonnenfeld, P., 1991. *Estimation of Homeless Caseload for Disaster Assistance due to an Earthquake*. SCEPP publication of a 1980 draft document originally prepared for FEMA: Pasadena, CA.
- EQE International and the Geographic Information Systems Group of the Governor's Office of Emergency Services, 1995. *The Northridge Earthquake of January 17, 1994: Preliminary Report of Data Collection and Analysis -- Part A: Damage and Inventory Data*. Governor's Office of Emergency Services of the State of California: Sacramento.
- Gideon, Siegfried. 1948. *Mechanization Takes Command*. Oxford University Press, New York.
- Harrauld, J.R., Abchee, M., Alharthi, H., and Boukari, D., 1991. *The Development of a Methodology for American Red Cross Staffing of a Disaster Under the Federal Response Plan*, Geo. Washington Univ. Research Report.

Harrald, J.R., Abchee, M., Cho, S., and Boukari, D., 1990. *Development of a Planning Methodology for Red Cross Catastrophic Earthquake Response*, Geo. Wash. Univ. Res. Rpt.

Harrald, J.R., Abchee, M., Cho, S., and Boukari, D., 1990. *An Analysis of the American National Red Cross Staffing for the Hurricane Hugo and the Loma Prieta Earthquake Disaster Relief Operations*, Geo. Washington Univ. Research Report.

Harrald, J.R., Abchee, M., Cho, S., and Scholarios, T., 1990. *Analysis of Narrative Reports for Hurricane Hugo and the Loma Prieta Earthquake*, Geo. Wash. Univ. Research Report.

Harrald, J.R., Fouladi, B., and Al-Hajj, S.F., 1992. *Estimates of Demand for Mass Care Services in Future Earthquakes Affecting the San Francisco Bay Region*: Prepared by George Washington University for the American Red Cross Northern California Earthquake Relief and Preparedness Project (NCERPP), 41 pp. plus appendices.

Hayden, Dolores. 1986. *Redesigning the American Dream: The Future of Housing, Work, and Family Life*. W.W.Norton & Co., New York.

Kostof, Spiro. 1985. *A History of Architecture*. Oxford University Press, New York.

Laird, R.T., Perkins, J.B. and others, 1979. *Qualitative Land-Capability Analysis*. USGS Professional Paper 945, p. 27.

Perkins, J.B., and Moreland, R., 1986. *Building Stock and Earthquake Losses—The San Francisco Bay Area Example*. ABAG: Oakland, 68 pp.

Perkins, J.B., 1987a. *The San Francisco Bay Area — On Shaky Ground*. ABAG: Oakland, CA, 32 pp.

Perkins, J.B., 1987b. *Maps Showing Cumulative Damage Potential from Earthquake Ground Shaking, San Mateo County, California*. USGS Map I-1257-I, 17 pp. plus 3 map plates, scale 1:62,500.

Perkins, J.B., 1992. *Estimates of Uninhabitable Dwelling Units in Future Earthquakes Affecting the San Francisco Bay Region*. ABAG: Oakland, California, 89 pp.

Perkins, J.B., 1994. *Existing Land Use in 1990: Data for Bay Area Cities and Counties*. ABAG: Oakland, California, 308 pp.

Perkins, J.B., and Boatwright, J., 1995. *The San Francisco Bay Area – On Shaky Ground*. ABAG: Oakland, California, 56 pp.

Richter, C.F., 1958. *Elementary Seismology*. W.H. Freeman and Company, San Francisco, pp. 135-149; 650-653.

State of California Department of Housing and Community Development, 1991. *Evaluation of Manufactured Housing Support System Performance in the Loma Prieta Earthquake*. Sacramento, CA, 14 pp.

Stover, C.W., Reagor, B.G., Baldwin, F.W., and Brewer, L.R., 1990. *Preliminary Iseisimal Map for the Santa Cruz (Loma Prieta), California, Earthquake of October 19, 1989 UTC*. U.S. Geological Survey Open-File Report 90-18, Denver, CO, 24 pp.

U.S. Bureau of the Census, May 1991. *Standard Tape File 1 (STF-1A)*.

U.S. Bureau of the Census, May 1992. *Standard Tape File 3 (STF-3)*.

Wells, D.L., and Coppersmith, K.J., 1994. "New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement" *in Bulletin of the Seismological Society of America*, v. 84, no. 4, pp. 974-1002.

Wood, 1908. "Distribution of Apparent Intensity in San Francisco" *in Report of the State Earthquake Investigation Commission* (Andrew C. Lawson, Chairman). Carnegie Institution of Washington, Washington, DC, pp. 220-227.

Wood and Neumann, 1931. "Modified Mercalli Intensity Scale of 1931" *in Bulletin of the Seismological Society of America*. Stanford University Press, Stanford, Vol. 21, pp. 227-283.

APPENDIX A -- CLASSIFICATION OF BUILDINGS

CLASSIFICATION DESCRIPTION

For the purposes of seismic analysis of the extensive Bay Area housing stock, buildings have been broadly classified according to three basic characteristics:

1. the nature of the building's structural system;
2. the configuration or shape of the building; and
3. the age of the building.

1. Structural Type

In very simple terms, the complete structural system of a building consists of vertical elements (such as columns and walls) and horizontal elements (such as floors, roofs, beams and girders). The material of these components, as well as the method by which they are connected, are fundamental in determining the essential characteristics of the structural system.

Because of the large variation in housing stock in the nine Bay Area counties, a detailed classification scheme which would take into account both horizontal and vertical elements of the structure, as well as the various methods by which they are connected, has not been used in this report. Rather, this project has focused on identifying the material and nature of the principal vertical structural elements. Thus, this report categorizes building structures according to the material of its principal vertical elements. This "material/structure" classification follows established groupings from the building industry. In the building industry, the nature of a structural system is generally classified according to the material of its components:

- **Light material;** includes wood frame, mobile homes, and light metal;
- **Masonry;** includes brick and concrete block (reinforced or unreinforced);
- **Steel frame;** includes braced frames and moment resisting frames, with and without concrete or masonry infill walls; and
- **Concrete;** includes cast-in-place and precast or a combination of the two.

Based on these definitions, this report classifies the various structural types according to the principal material of which the structure is built. Thus, a wood frame is classified as a "Wood" structure; a concrete structure, whether precast or poured-in-place, is classified as "Reinforced Concrete"; masonry buildings are classified as either "Unreinforced Masonry" or

"Reinforced Masonry" structures; and a steel frame building is classified as a "Steel Frame" structure.

It should be noted that the common multi-family type building which consists of a concrete podium with a wood frame of several stories above has been classified within the wood-frame category: "Wood."

Two classifications used in the report which do not follow the above rules are the categories of "Mobile Homes" and "Other." Since Mobile Homes are accounted for in the U.S. Census and are a clearly distinguishable building type with particular seismic concerns, they have been classified into a category of their own. The category defined as "Other" in the report does so according to the definition of the U.S. Census; "Other" is used in the U.S. Census when a householder lives in a structure other than in the alternatives defined by the Census Bureau. This option includes shelters such as boats, tents, caves, or railcars.

Based on these issues, this report classifies the structure type of a building into the following categories:

- Mobile Homes (MH)
- Wood (Wd)
- Unreinforced Masonry (URM)
- Reinforced Masonry (RM)
- Reinforced Concrete (RC)
- Steel Frame (SF)
- Other

Since wood-frame buildings are by far the largest component of the housing stock in the Bay Area (they account for up to 93% of the area's housing stock), the structural types have been further broken down to wood and non-wood classifications. The combined three structure types of Reinforced Concrete, Reinforced Masonry and Steel Frame represent only 2% of the Bay Area's total housing stock and they have therefore been consolidated into a single structural type: non-wood.

The five categories used in this report to classify the type of structure of the Bay Area's housing stock are:

- Mobile Homes, which represent 3% of the total;
- Unreinforced Masonry, which represent 1%;
- Wood, which represent 93%;
- Non-wood, which represent 2%; and
- Other, which represent 1%.

2. Configuration

While the structure of a building plays an important role in the mitigation of seismic forces, its configuration will likewise influence its earthquake resistance. Configuration deals with issues such as building height, building shape and general width-to-height proportions. It might also include the location and arrangement of the major structural elements within the building. Due to the size of the Bay Area's housing stock, and due to the fact that height is perhaps the most important element in a building's configuration, this report categorizes a building's configuration only by its height. Accordingly, for the purposes of this report, the height of a building determines whether it is classified as:

- Low (L); three stories and under
- Medium (M); between four and seven stories
- High (H); eight stories and over

When classifying a building according to its height, parking levels have consistently been included. Whether the parking level is below grade, half a level below grade, or above grade, it has been included in the story count of a building. Thus, for example, a building with three stories of living space and a first story of parking is considered as a four story building, or a "Medium" (M) height building.

3. Age

The age of construction plays an important role in the seismic performance of buildings. Over time, building technologies have improved, and code requirements have increased. The age of a building can give clues as to how buildings were detailed and put together. The age of a building can also suggest information about the quality of the materials used and the quality of the craftsmanship during construction. Since significant changes in construction practices were typically triggered by earthquakes, the age of a building determines whether construction occurred before or after a code change or before or after the use of a particular building technology. Age therefore can serve as an indicator of how well a building will resist earthquakes in the future.

It is generally accepted that changes in construction practices and codes occurred after World War II (W.W.II). Some of the first construction legislation predated W.W.II and was triggered by earthquakes: the Long Beach earthquake of 1933 triggered the Field Act

and the Riley Act; the Uniform Building Code was first published and organized in 1927. However, almost three-quarters of the total housing stock in the United States has been built since 1940 and changes in construction practices, particularly in housing construction, did not take place until after W.W.II with the massive suburbanization of cities, and the increased demand for single family dwellings (Hayden, 1986). In the San Francisco Bay Area this number is slightly higher; almost 80% of the region's housing stock was built after 1940.

The extensive use of plywood and other modern building materials, together with the wider existence and implementation of building codes, occurred with the large scale developments following the war. Although certain building regulations were in place before the beginning of W.W.II, and certain construction technologies were already in existence by the time of the war, it was not until the suburbanization of cities and the increased demand for housing that there were significant changes in construction practices (Gideon, 1948; Kostof, 1985; Hayden, 1986).

The significance of W.W.II as the cut point for this report in the classification of building age is corroborated by preliminary statistics from the Northridge earthquake. Insurance company statistics on percentage losses to single family homes show that there was no significant difference in performance by year of construction other than pre- and post-W.W.II buildings. These companies speculate that, to some degree, improvements in the codes and construction practices have been offset by the extensive use of complex configurations, large amounts of glass and cathedral ceilings in newer construction (personal communication, Robert Downen).

One of the most noticeable differences between pre- and post-1940 buildings is the degree of parking within both multi-family and single family buildings. It is common for most multi-family buildings built after W.W.II to have either the entire ground floor or most of it dedicated to parking.

At the same time, owner-occupied units have been getting larger and larger in each decade since W.W.II; in 1976, 84% consisted of five or more rooms (Hayden, 1986).

Although 1940 has been identified as the key cut-off point for the report, the actual decade of construction has been catalogued for each entry. In addition, when the information was available and a precise record of construction existed, it was catalogued. Typically, the decade of construction was identified through field visits or from data obtained from building departments. Hence, a building built in 1936 has been identified as a 1930s building; a building built in 1967 as a 60s building, a building built in 1940 as a 40s building, and so on.

While the age of buildings has been identified by decade or by year, the report classifies building age according to if they are pre- or post-W.W.II (1940s) vintage. Based on the developments in the building codes and construction practices described above, World War II or, in terms of decades, 1940, has been identified as a

turning point in the development of construction practices.

This report classifies the age of buildings according to two periods:

- pre-1940
- 1940 to present

A CLASSIFICATION FOR BUILDING TYPES

For the purposes of this study, then, the buildings of the existing housing stock have broadly been classified according to the three sets of categories described above: the *material* of the structure of the building, the *height* or *number of stories* of the building, and the *age* of the building. These three categories enable classification of the Bay Area’s housing stock into the following thirteen building types:

TABLE A1 -- SUMMARY OF CHARACTERISTICS OF BUILDING TYPES USED IN THIS REPORT

Building Type	Structure	Configuration	Age	Single vs. Multi-Family	% of Total	% of Multi-Family
Type 1	Mobile Homes	1-3 stories	Post 1940	Single-Family	2.8%	
Type 2	Unreinforced Masonry	Varies	Pre 1940	Multi-family	1.0%	2.9%
Type 3	Non-Wood	4-7 stories	Pre 1940	Multi-family	0.2%	0.5%
Type 4	Non-Wood	4-7 stories	Post 1940	Multi-family	0.2%	0.6%
Type 5	Non-Wood	8 and up	Pre 1940	Multi-family	0.1%	0.5%
Type 6	Non-Wood	8 and up	Post 1940	Multi-family	1.0%	3.0%
Type 7	Wood	4-7 stories	Pre 1940	Multi-family	1.0%	2.8%
Type 8	Wood	4-7 stories	Post 1940	Multi-family	2.3%	6.9%
Type 9	Wood	1-3 stories	Pre 1940	Multi-family	6.9%	20.2%
Type 10	Wood	1-3 stories	Post 1940	Multi-family	21.3%	62.6%
Type 11	Wood	1-3 stories	Pre 1940	Single-Family	8.3%	
Type 12	Wood	1-3 stories	Post 1940	Single-Family	53.6%	
Type 13	Other	Varies	Varies	Varies	1.3%	

Type 1:
Mobile Homes

A mobile home is a factory-built dwelling built entirely of light-weight metal construction or a combination of a wood and steel frame structure. When combining wood and steel, the wood frame structure is erected on a steel frame chassis. In either case, the exterior is typically protected with siding of wood, aluminum or fiberglass. Mobile homes are often structurally linked to a second unit forming a double-wide coach. The units can be pulled on wheels to a site, leveled, and supported in one of the following ways.

1. The coach can rest on the ground with only small metal devices called screwjack levels between it and the soil. The screwjack level consists of a metal triangle shaped base, similar to a tripod, with a screw and plate to connect it to the coach.
2. The coach can be supported above ground by resting on piers which are generally spaced about six feet apart. The undercarriage is leveled between these piers with screwjack levelers or wood blocks (called shims). The piers are made of concrete, steel, unreinforced concrete, or cinderblock. These piers can rest on either a concrete slab or on treated wood that sits directly on the ground.
3. The coach can be supported by reinforced concrete foundation units at the corners coupled with tie down connections to its frame.

Mobile home units statistically tend to be subject to greater damage from equivalent intensities of shaking than do wood-frame dwellings. In an earthquake, the typical jacks on which the coach is placed will tip, and the coach will fall off some or all of its supports. It is not uncommon for the jacks to punch holes through the floors of the coach in this process. The mobile home unit usually remains relatively undamaged. The major problem is that even at these relatively low damage amounts, the mobile home becomes uninhabitable; it must be returned to a foundation, re-leveled and reconnected to utilities. A corner foundation would typically prevent the coach from falling off its base and the damage would be less severe.

Mobile homes comprise only 2.8% of the total Bay Area housing stock. Their presence varies significantly by county. The county with the most mobile homes is Santa Clara, with 30.7% of the mobile homes in the region. However, within this county they comprise only 3.8% of the total housing stock. On the other hand, the counties of Napa and Sonoma have the highest percentage of mobile homes: 8.8% and 7.3% respectively.



Typical Mobile Home Damage
Source: Karl Steinbrugge

Type 2:
Unreinforced Masonry

Unreinforced masonry (URM) buildings consist of structures in which there is no steel reinforcing within a masonry wall. The definition of an unreinforced masonry building varies from city to city. Some cities classify unreinforced infill walls within a reinforced frame as a URM while others classify unreinforced exterior veneers on to a wood frame as URM. For this report, URM buildings are those which have bearing walls of unreinforced masonry. Floors, roofs and internal partitions in these bearing wall buildings are usually of wood.

These buildings were constructed in an era when reinforcing was generally not used. Anchorage to floor and roof was generally missing and the use of low strength lime mortar was common. Construction of reinforced masonry became common sometime between 1933 and 1955, depending on local codes and stringency of code enforcement.

Earthquake damage to unreinforced masonry structures can be severe and hazardous. The lack of reinforcement coupled with poor mortar and inadequate roof-to-wall ties can result in substantial damage to the building as a whole as well as to specific sections of it. Severely cracked or leaning walls are some of the most common earthquake damage. Also hazardous, but slightly less noticeable, is the damage that may occur between the walls, and roof and floor diaphragms. Separation between the framing and the walls can jeopardize the vertical support of roof and floor systems which could lead to the collapse of the structure.

Housing units in URM buildings account for only 1% of the total Bay Area housing stock and 2.9% of the total Bay Area multi-family stock. Their presence is significant in the County of San Francisco where they account for 5.8% of the total stock. Their significance is magnified if these numbers are compared only with the multi-family totals: in San Francisco County, URM represent 8.7% of its multi-family stock. Similarly, although URM account for only 0.9% of the housing units in Alameda County, they represent 2.3% of the multi-family stock.

Type 3:
Non-wood, Four to Seven Stories, pre-1940

Generally, these buildings consist of cast-in-place concrete buildings built during the 1930s. These apartment buildings typically follow one of two concrete construction systems: either cast-in-place reinforced concrete bearing walls or, cast-in-place concrete frames.

Pre-1940 apartment buildings constructed out of a concrete moment-resisting frames are rare. These buildings often include infill masonry walls which usually consist of hollow clay tile or brick. In pre-1940 buildings, the infill walls are often not reinforced and susceptible to becoming falling hazards in the event of an earthquake. In general, these types of concrete structures, where reinforcing was not detailed nor installed to give ductile performance, have performed poorly in earthquakes. This type of structure is subject to collapse in the event of an earthquake.

On the other hand, concrete bearing wall construction can have sound seismic force resisting characteristics. Typically, walls are poured to the level below the floor, then a floor slab is poured, and then the next portion of the wall is poured. The quality of the construction joints between pours become critical. Since the older concrete bearing-wall structures were constructed before the widespread use of plywood, the impression of the horizontal form boards are often left on the exterior walls of the building.

Pre-1940 bearing-wall cast-in-place concrete buildings have performed very well in earthquakes even though they may not have been intentionally designed to resist them. However, in all concrete buildings, non-structural damage to elevators and plumbing may occur.

The only county where the number of units of this building type approach 1% of the local housing stock, is San Francisco. Even in this county, they account for only 1.5% of the multi-family housing stock. In the total Bay Area, Type 3 buildings account for barely 0.2% of the total housing stock. It should be reiterated that the combined non-wood building types, Type 3 through Type 6, account for only 2.5% of the total Bay Area housing stock, and that they are mainly present in the older and denser cities of the region.

Type 4:

Non-Wood, four to seven stories, post-1940

This building type includes a wide variety of construction systems and materials. Even though combinations of materials are common, perhaps the most typical structural systems within this category can be classified as either being reinforced concrete (bearing wall or frame structures), reinforced masonry, or steel frame structures. Precast concrete apartment buildings under seven stories are generally less common.

Most of the buildings in this building type date from the 1960s. The 1960s was an era in which there were some innovations in construction and when the construction of multi-family buildings was extensive. Multi-family buildings under seven stories with the primary structural material being something other than wood or reinforced concrete are generally from this period.

A construction system generally identified with the 1960s is that of reinforced masonry or concrete block bearing walls. This construction system involves the use of concrete blocks, or concrete masonry units (CMU) to form walls which are reinforced with steel bars and then filled with concrete. These walls are usually bearing, but can also serve as shear walls. Floor and roof diaphragms may be constructed in a variety of ways. Among the more common are steel decking with or without concrete fill, cast-in-place concrete and glulam and plywood floors. Usually these buildings are easily identified by their form: typically they are rectangular in plan, have flat roofs, and have exterior circulation balconies. Also, most often the CMUs are left exposed.

Reinforced masonry buildings are subject to far less damage than unreinforced masonry structures. Diagonal cracking of walls, particularly of shear walls and columns, indicate a loss of strength. Corner cracking in CMU walls at door and window openings can jeopardize the vertical support of floor and roof framing. In addition, separation between the horizontal diaphragms and the shear and bearing walls connections may occur.

Reinforced concrete or steel frame apartment buildings under seven stories are far less common than CMU construction during this period.

Although buildings seven stories and under, with a concrete parking podium which supports a wood frame above, are widespread during the post W.W.II period,

for the purposes of this study, these buildings are classified as wood structures.

Of greater concern are the pre-1971 reinforced concrete moment-resisting frame buildings. These buildings were constructed prior to the 1971 San Fernando Earthquake which resulted in new ductility requirements in the codes. Concrete moment-resisting frames gained popularity during the 1950s when designers treated concrete as a steel frame. As mentioned above, these buildings are subject to collapse in the event of an earthquake.

Steel frame apartment buildings between four and seven stories exist, but are rare. They usually will date from the 1960's, when different construction systems were tried. The lateral forces can be resisted by a braced frame, a moment-frame, or masonry or concrete-infill shear walls. In the case of braced-frame structures, diagonal bracing typically buckles, stretches, or pulls apart at the connections. After the braces buckle, deformations of the structure could become large with the consequence of greater damage.

Moment-resisting steel frames might experience considerable side sway under a severe earthquake. Severely damaged moment-frame structures may have a residual story drift causing the entire building to remain out of plumb. Steel frames with concrete or masonry shear walls have had the best experience of any type of large structure. Wall stiffness limits motion and consequent drift damage. While walls might crack, repair costs are low.

In the 1980s, the combined use of materials, namely concrete, wood and steel, is more common in multi-family housing buildings above four stories. Wood structures that include a one or two story concrete platform, with a wood frame that has steel elements within it, is common in apartment buildings between five and seven stories. As the building increases in height so do the steel elements within it.

As with Type 3, units in Type 4 buildings account for only 0.2% of the total Bay Area housing stock. Their presence is significant only in the denser parts of the region. Even in San Francisco, they represent less than 1% of the total stock and only 1.1% of the multi-family stock.

Type 5:
Non-wood, over 7 stories pre-1940

Similar to the pre-1940 buildings under seven stories (building Type 3), pre-1940 non-wood buildings over seven stories consist primarily of cast-in-place concrete bearing wall structures or steel frame with unreinforced masonry infill wall structures.

Concrete bearing-wall construction can have good seismic force resisting characteristics. Walls are poured to the level below the floor, then a floor slab is poured, and finally the next portion of the wall is poured. Typically, pre-1940 concrete bearing wall buildings are under 10 stories. Examples of this building type exist in the older cities of the Bay Area, particularly San Francisco, Oakland and Palo Alto.

Since the older concrete bearing-wall structures were constructed before the use of plywood, the impression of the horizontal form boards are often left on the exterior walls of the building. Older concrete buildings with cast-in-place concrete walls have performed very well in earthquakes even though they may not have been intentionally designed to resist them. However, non-structural damage to elevators and plumbing may occur in all concrete buildings.

Steel frame with unreinforced masonry infill walls generally perform well in avoiding collapse. However the unreinforced infill walls present life safety risk in the form of falling hazards. The infill walls may be difficult to identify as they may be covered with plaster. Large cracks in them indicates a potentially unsafe situation.

Units in buildings within this category represent only 0.1% of the total Bay Area housing stock. In San Francisco County they represent 1% of the total and 1.5% of the multi-family stock. This building type is non-existent in Contra Costa, Marin, Napa, San Mateo, Solano and Sonoma counties.

Type 6:
Non-wood, over 7 stories post-1940

Similar to the post-1940 buildings under seven stories, building Type 6 includes a wide variety of construction systems. In addition to the systems described under building Type 4 (steel frame, reinforced masonry and poured-in-place reinforced concrete), the use of pre-cast reinforced concrete has occurred in apartment buildings above seven stories, particularly large elderly housing complexes.

Precast concrete structures are constructed by either welding steel together at the connections or by pouring in place concrete closure strips at the connections of the precast elements. Various portions of the structure may be poured-in-place concrete, including topping slabs. Beams, columns and exterior panels are often precast.

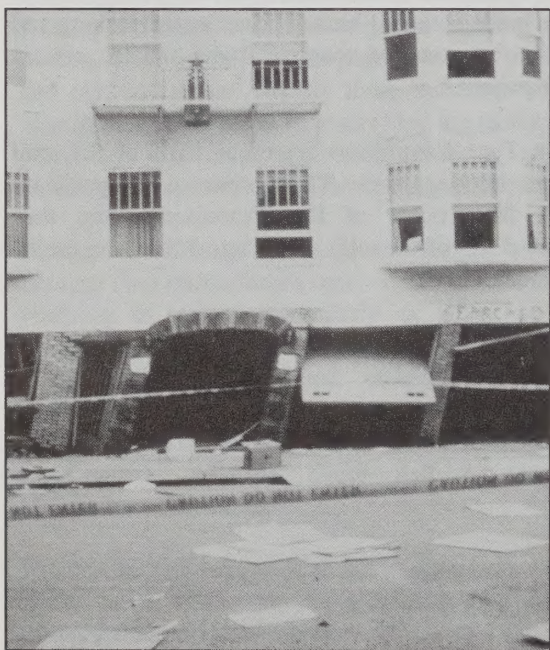
The principal seismic concerns with precast elements are the joints and connections of the precast elements. While precast buildings may sustain actual forces several times greater than the design levels, the joints may not have the necessary strength and ductility to withstand the event without damage or separation. Precast concrete beams with cracking at the joint with the column represents a potential loss of vertical support for the beam and the structure as a whole. Also of concern is the potential hazard posed by the racking and separation between the concrete frame and the precast exterior panels.

Units in Type 6 buildings represent 1.0% of the total Bay Area housing stock. Their presence is significant only in the County of San Francisco where they represent 5.3% of the total stock, and 8% of the multi-family stock.

Type 7:
Wood, 4-7 stories pre-1940

Most buildings in this category are four-story apartment complexes. As opposed to the post-1940 four-story apartment buildings, most of the pre-1940 four-story buildings are constructed entirely of wood. Typically framed with wood posts, wood joists and stud walls, the exterior walls are usually reinforced with 1x diagonal sheathing boards. These buildings often lack appropriate shear strength at the base of the structure so that in severe earthquakes they may rack. Also of concern is the connection to the foundation. These buildings often lack appropriate foundation anchorage and the building can move off its foundation under strong shaking. Cracking in the foundation may also occur due to a lack of appropriate reinforcement within it.

Units in Type 7 buildings are a significant part of the housing stock in the older cities in the Bay Area. In the County of San Francisco they account for 6.9% of the total housing stock and 10.5% of the multi-family stock. However, over the entire Bay Area, they comprise only 1% of the housing stock.



Damage to Pre-1940 Wood Apartments
Source: California Governor's Office of Emergency Services

Type 8:
Wood, 4-7 stories post-1940

A significant percentage of the Bay Area's multi-family housing stock falls within this category. Type 8 buildings include a high number of the multi-family structures built in the Bay Area during a period of intense urban growth.

This building type includes wood frame structures built over a first-story concrete podium used entirely for parking. As was mentioned earlier, this is a common design formula for many apartment buildings in the Bay Area, and California in general. The podium structure usually consists of walls or columns of either reinforced concrete or concrete masonry units (CMUs) supporting a concrete slab. The wood frame sits on the reinforced concrete slab, and as the building increases in height, so does the use of steel within the wood frame.

Bearing CMU walls are generally identified with the 1960's. This construction system involves the use of concrete blocks to form walls which are reinforced with steel bars and then filled with concrete. During the 1960s, but to a lesser degree after that, these walls were usually bearing. CMU walls can also serve as shear walls.

In these wood-frame-over-parking buildings, the parking level, whether it is reinforced concrete or reinforced masonry, will usually perform in accordance with its design and detailing. Any full or partial collapse of this underlying structure will result in damage similar to ground failure under more typical wood buildings. Although the shaking of the wood portion of the construction will be amplified by the base shaking, this portion of the building will otherwise perform in accordance with other wood dwellings.

Over the total Bay Area, 7.1% of the multi-family housing stock falls within this category. San Mateo County has the highest percentage of dwelling units within this category: 5.4% of the total units and 17% of the multi-family units. In an older region such as the County of San Francisco, they represent only 5.7% of the multi-family stock. Type 8 buildings represent 2.3% of the total Bay Area housing stock.

Type 9:

Wood, 1-3 stories multi-family pre-1940

Most buildings in this category have lower onsite parking requirements relative to those of today. The first floor is therefore generally used as living space, half a level above grade to establish a degree of separation between the street and private areas within the building.

Similar earthquake safety issues apply to this category as to category 7: poor foundation anchorage and reinforcing. In addition, it is not uncommon for pre-1940 apartment buildings to include chimneys. These are often unreinforced and lack proper ties to the structure. They may break off or fall inwards onto roofs or rafters causing further damage.

The older more established regions of the Bay Area include the highest percentage of units of this building type. In San Francisco County, units in Type 9 buildings represent 25.9% of the total housing stock, and 39.2% of the multi-family stock. Units in buildings under 3 stories built prior to 1940 seem to be the most common form of shelter in San Francisco County for they account for the highest percentage of all building types. In Alameda County, they represent 9.5% of the total housing stock, and 24.9% of the multi-family stock.

Type 10:

Wood, 1-3 stories multi-family post-1940

Since these buildings were built at a time when significant parking requirements were in place, it is extremely common for these buildings to have either most or all the first level dedicated to parking. The typical design formula has been that of two levels of living space over either on grade, half a level below grade, or below grade parking. In each case, the living area is usually supported only by posts, typically steel tubes, with a 4x girder connecting them. Also common in this category are three story buildings where the parking level is constructed out of concrete masonry unit (CMU) bearing walls. As the Northridge Meadows Apartments have shown, this design formula can offer little resistance to the lateral seismic forces. The performance of the parking structure in past earthquakes has not been good.

Three-story multi-family buildings with the first level dedicated to parking are a fairly new phenomena. In some of the more recently urbanized areas of the Bay Area, as in most of Santa Clara and Contra Costa counties, there is a high percentage of these types of buildings. In Santa Clara County for example, they account for 27% of the total housing stock. Often they are only 20 or 25 year old buildings and have not been exposed to significant seismic forces yet. Three story buildings with a "soft" first story are vulnerable to lateral forces as there typically is inadequate lateral bracing at the ground level in a non-moment-resisting frame.

Over the entire Bay Area, units in Type 10 buildings represent 21.3% of the total housing stock. Their numbers are particularly significant in some of the more recently urbanized counties; in Contra Costa and Santa Clara counties, for example, they represent 88.5% and 87.1% of the multi-family stock.



Damage to "Modern" Apartment Complex

Source: Jeanne Perkins

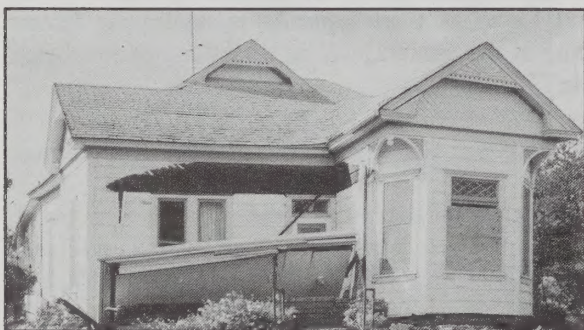
Type 11:

Wood, 1-3 stories single-family pre-1940

A typical problem with houses built during this era is the connection between the wood frame and the foundation. These houses often lack steel bolts or any other type of “tie-down” between the foundation and the wood frame. Since these houses were built before the widespread use of plywood, they also typically lack appropriate shear reinforcing at the cripple walls (the walls between the top of the foundation and the floor diaphragm). Finally, steel reinforcing often is not found both in the foundation of these houses as well as in their chimneys. Some of these older houses may be only founded on brick with weakly cemented joints.

Typical earthquake damage to these structures includes the wood frame coming off its foundation, the foundation itself cracking, the chimney breaking at the roof line, or the cripple walls racking. Because this type of damage is so common, earthquake hazard mitigation efforts in most building departments are directed toward them.

Pre-1940 single family dwellings account for 8.3% of the total Bay Area housing stock. Their relative numbers are highest in the counties of San Francisco and Alameda where they account for 14.9% and 11.7% of the total housing stock.



Typical Damage to Older Wood-Frame Home

Source: Jeanne Perkins

Type 13: Other

The category defined as “Other” in the report does so according to the definition of the U.S. Census; “Other” is used in the U.S. Census when a householder lives in a structure other than in the alternatives defined by the Census Bureau. This option includes alternative types of shelter such as boats, tents, caves, or railcars. However, the Census data is merely a compilation of questionnaires filled in by residents. Unfortunately, the

Type 12:

Wood, 1-3 stories single-family post-1940

This category accounts for the suburban California house that is familiar to most of us. Built after W.W.II with increasingly larger garages, our single family house has increased in square foot size over the years. A common design formula for post W.W.II single family house has been locating the living spaces above a two car garage that faces the street. This strategy often produces long spans for the floor and roof diaphragms making the structure more vulnerable during an earthquake.

Although the post-1940 house does not present widespread problems with foundation anchorage and foundation reinforcing, there often is a lack of proper reinforcement of the masonry chimneys. A significant number of post-1940 dwellings can be yellow tagged because of some type of chimney damage or partial structural failure due to long spans over the garage.

The post-1940 house accounts for 53.6% of the total Bay Area housing stock. Its relative numbers are most significant in the more recently urbanized counties of the Bay Area: Contra Costa County 68.3%, Marin County 59.9%, Napa County 62.6%, San Mateo County 58.6%, Santa Clara County 61.2%, Solano County 67.3% and Sonoma County 64.9%.



Typical Damage to Newer Wood-Frame Home

Source: Degenkolb Associates

“Other” category became a catch-all which, in the minds of those filling out the questionnaire, also included flats, single-room-occupancy hotels, condos and homeless. This number is therefore high, but we have no data to correct it. However, because we did have data on the larger structures, these extra units result in an undercounting of newer single-family wood, not more complex or vulnerable structures.

APPENDIX B -- SUPPLEMENTARY INFORMATION ON INTENSITY SCALES AND INTENSITY MODEL ACCURACY

The intensity model was scaled against the shaking attenuation curve of Borchardt, Gibbs and Lajoie (1975) derived from 1906 intensity data using this intensity scale developed specifically for the 1906 earthquake. One of the obstacles in developing damage values for this project is how to correlate this intensity scale developed for one earthquake with a more common scale for which statistical damage data are available on damage in several past earthquakes. This correlation has to be based, unfortunately, not on statistical percentages of damages to a type of construction in a given area for a particular earthquake, but on verbal descriptions of damage associated with a range of intensities using separate intensity scales.

The three intensity scales of interest are San Francisco intensity (used in the report on the San Francisco earthquake by Wood, 1908 and thus in the Borchardt, Gibbs and Lajoie document), Rossi-Forel intensity (Richter, 1958), and modified Mercalli intensity (Wood and Neumann, 1931). The definitions of the three scales are supplied in Tables B1 - B3.

Use of these scales has been complicated by the way in which, with some overlap, each particular scale is most associated with data from earthquakes in given time periods. Thus, because the strength of different types of building construction have changed over time, statements of the damage to buildings contained in the narrative descriptions of these scales make it extremely difficult to correlate among them.

Richter (1958) and Wood and Neumann (1931) provide a rough correlation between Rossi-Forel intensity and modified Mercalli intensity, while Wood (1908) includes a correlation between San Francisco intensity and Rossi-Forel intensity. (See Figures 1a and 1b.) No *direct* correlation between San Francisco intensity and modified Mercalli intensity levels were ever produced by these authors and published in this literature.

The temptation is to somehow assign numerical values to the various letters and Roman numerals and "scale" the scales, coming up with values such as C.5 = VIII.33. The artificial nature of this mathematical "accuracy" becomes apparent if one goes back to the original references and reads the subjective original definitions of each of these three scales. Even scaling these scales graphically, to produce a graph (such as in Figure 2) can easily misrepresent the intent of these scales.

These original authors fully understood the subjective nature of the scales. They never used numbers in the scales, making a point of using either Roman numerals or letters. Even when forced to relate the scales, the authors used "+" and "-" symbols or graphic representations.

Another problem with comparing these intensity scales with the values produced in these modeled maps is that the modeled maps are far more detailed than an intensity map. Thus, if an area of soft soil is surrounded by rock, the model maps will assign the soft soil area to a higher intensity, while the intensity maps typically will include that pocket in with the rock, showing the entire area falling within the lower intensity.

TABLE B1 -- THE SAN FRANCISCO INTENSITY SCALE
[from Wood, 1908]

Grade A. Very Violent	Comprises the rending and shearing of rock masses, earth, turf, and all structures along the line of faulting; the fall of rock from mountain sides; numerous landslips of great magnitude; consistent, deep, and extended fissuring in natural earth; some structures totally destroyed.
Grade B. Violent	Comprises fairly general collapse of brick and frame buildings when not unusually strong; serious cracking of brick work and masonry in excellent structures; the formation of fissures, step faults, sharp compression anticlines, and broad, wave-like folds in paved and asphalt-coated streets, accompanied by the ragged fissuring of asphalt; the destruction of foundation walls and underpinning structures by the undulation of the ground; the breaking of sewers and water-mains; the lateral displacement of streets; and the compression, distension, and lateral waving or displacement of well-ballastered street-car tracks.
Grade C. Very Strong	Comprises brick work and masonry badly cracked, with occasional collapse; some brick and masonry gables thrown down; frame buildings lurchd or listed on fair or weak underpinning structures, with occasional falling from underpinning or collapse; general destruction of chimneys and of masonry, brick or cement veneers; considerable cracking or crushing of foundation walls.
Grade D. Strong	Comprises general but not universal fall of chimneys; cracks in masonry and brick work; cracks in foundation walls, retaining walls, and curbing; a few isolated cases of lurching or listing of frame buildings built upon weak underpinning structures.
Grade E. Weak	Comprises occasional fall of chimneys and damage to plaster, partitions, plumbing, and the like.

TABLE B2 -- THE ROSSI-FOREL SCALE
[from Richter, 1958]

I. Microseismic Shock.	Recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.
II. Extremely Feeble Shock.	Recorded by several seismographs of different kinds; felt by a small number of persons at rest.
III. Very Feeble Shock.	Felt by several persons at rest; strong enough for the direction or duration to be appreciable.
IV. Feeble Shock.	Felt by persons in motion; disturbance of movable objects, doors, windows, cracking of ceilings.
V. Shock of Moderate Intensity.	Felt generally by everyone; disturbance of furniture, beds, etc., ringing of some bells.
VI. Fairly Strong Shock.	General awakening of those asleep; general ringing of bells; oscillation of chandeliers; stopping of clocks; visible agitation of trees and shrubs; some startled persons leaving their dwellings.
VII. Strong Shock.	Overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.
VIII. Very Strong Shock.	Fall of chimneys; cracks in the walls of buildings.
IX. Extremely Strong Shock.	Partial or total destruction of some buildings.
X. Shock of Extreme Intensity.	Great disaster; ruins; disturbance of the strata; fissures in the ground, rock falls from mountains.

TABLE B3 -- MODIFIED MERCALLI INTENSITY SCALE
[from Richter, 1958]

I.	Not felt. Marginal and long period effects of large earthquakes.
II.	Felt by persons at rest, on upper floors, or favorably placed.
III.	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV.	Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frame creak.
V.	Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
VI.	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visibly, or heard to rustle).
VII.	Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
VIII.	Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX.	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. (General damage to foundations.) Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluvial areas sand and mud ejected, earthquake fountains, sand craters.
X.	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI.	Rails bent greatly. Underground pipelines completely out of service.
XII.	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

Masonry A: Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B: Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Masonry C: Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.

Masonry D: Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

FIGURE B1 -- (a) COMPARISON OF SAN FRANCISCO INTENSITY VS. ROSSI-FOREL INTENSITY AND (b) ROSSI-FOREL INTENSITY VS. MODIFIED MERCALLI INTENSITY

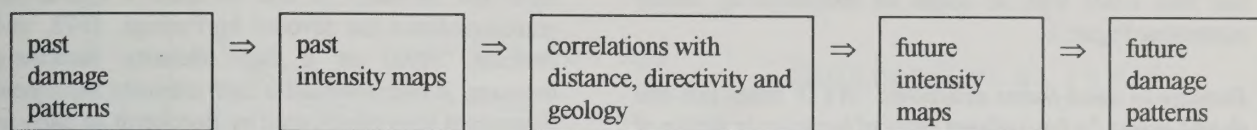
[(a) from Wood, 1908, p. 226 and
(b) from Wood and Neumann, 1931, pp. 280-281; Richter, 1958, p. 651]

a --		b --	
SAN FRANCISCO SCALE	ROSSI-FOREL SCALE	ROSSI-FOREL SCALE	MODIFIED MERCALLI SCALE
Grade A	10	10	X - XII
Grade B		9+	IX
	9	8+ TO 9-	VIII
Grade C		8-	VII
Grade D	8	6 TO 7	VI
Grade E	7		

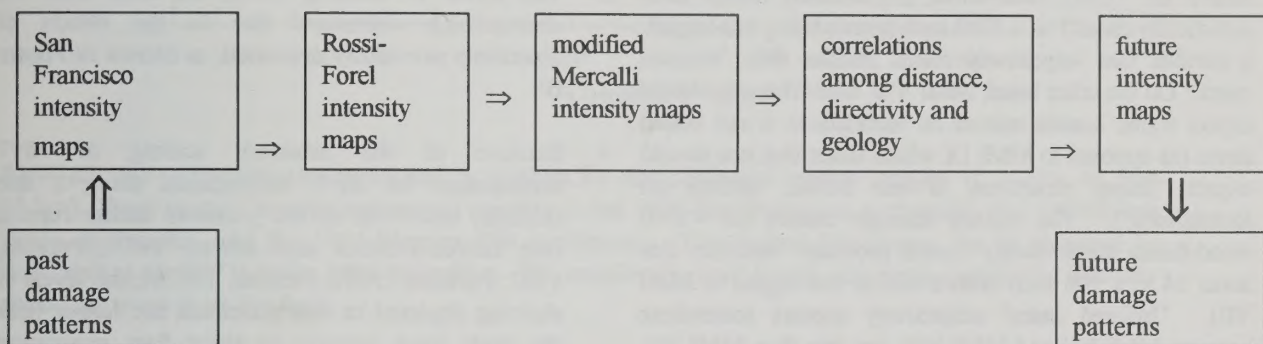
FIGURE B2 -- GRAPHIC SCALE OF SAN FRANCISCO INTENSITY VS. MODIFIED MERCALLI INTENSITY

SAN FRANCISCO INTENSITY	MODIFIED MERCALLI INTENSITY
A	XII
	XI
B	X
	IX
C	VIII
	VII
D	VI
E	

Finally, since the major purpose of intensity mapping is to predict damage in future earthquakes, the process becomes needlessly circuitous:



For 1906 data, the process is most circuitous for two more steps are added:



Given these problems, it is still essential that some type of correlation of damage data from the 1906 San Francisco earthquake to modified Mercalli intensity be developed in order to cross-check the results of the modeling process.

Matching, or scaling, the curve derived from the fault source model described in the previous section to the curve derived by Borchardt et al. (1975) "fixes" the relative position of the fault source model curve to the y-axis for San Francisco intensity. However, this does not directly translate to modified Mercalli intensity without more information than the charts supplied by Wood (1908), Wood and Neumann (1931), and Richter (1958). Thus, one cannot check the scaling of the model to the 1989 Loma Prieta earthquake damage and to the 1908 San Francisco earthquake damage data without assuming that *some movement of the entire curve relative to the y-axis is possible (and of unknown extent) due to the change of intensity scales being used*. Prior to the Loma Prieta earthquake, one of the authors had concluded that the offset of the two scales ranged from none (that is, SFI C = MMI VIII) to a half unit lower (that is, SFI C = the top of MMI VII to the bottom of MMI VIII). (See Laird and Perkins et al., 1978; Perkins and Moreland, 1986; Perkins, 1987a; Perkins, 1987b).

The value of the ground motion was first correlated against the curve developed from 1906 data by Borchardt et al. (1975).

Next, we used red-tagged matrices developed for modified Mercalli intensity levels to generate the "best fit" of the steeper curve for the 40 km long fault source for the 1989 Loma Prieta earthquake relative to the y-axis. This fit requires that the entire curve be raised 0.5 intensity increment on the y-axis. This shift is the opposite in direction of that which appears most likely given Figures 1a, 1b and 2. Thus, SFI C = the top half of MMI VIII to the bottom half of MMI IX. (See the table on page 41.)

However, we are not concerned about the need for this shift because, when reading and comparing the original descriptions of MMI and SFI, the shift does not appear unreasonable. One can compare the descriptions of, for example, damage to chimneys, wood-frame structures and unreinforced masonry buildings.

Chimney damage: SFI D states that one should expect "general, but not universal fall of chimneys." MMI VII states that one should expect "Weak chimneys broken at roof line." SFI D subjectively appears more intense than MMI VII. Similarly, SFI C states that one should expect

"general destruction of chimneys" while MMI VIII states that one should expect "fall of chimneys," leading one subjectively to conclude that SFI C is at least MMI VIII, not less than MMI VIII, as might be concluded by merely examining Figure 2.

Damage to wood-frame structures: SFI D states that one should expect "a few isolated cases of lurching or listing of frame buildings" while MMI VII makes no mention of damage to such structures. In fact, the red-tag damage matrix for <1940 wood-frame single-family homes talks statistically about 1 in a 1000 such homes being red-tagged, a number that subjectively seems smaller than "isolated cases." On the other hand, MMI VIII states that one should expect frame houses moved on foundations if not bolted down (as opposed to MMI IX which states that one should expect "frame structures, if not bolted, shifted off foundations"). The red-tag damage matrix for <1940 wood-frame single-family homes provides statistics that about 14 in a 100 such homes will be red-tagged in MMI VIII. "Isolated cases" subjectively appears somewhere between MMI VII and MMI VIII, not less than MMI VII, as might be surmised by Figure 2.

Damage to unreinforced brick buildings (Masonry C): SFI C states that one should expect "masonry badly cracked, with occasional collapse." MMI VII mentions "Some cracks in masonry C," MMI VIII mentions "damage to masonry C" and MMI IX mentions "masonry C heavily damaged, sometimes with complete collapse." Again, subjectively, SFI C appears to be somewhere between MMI VIII and MMI IX, not between MMI VII and MMI VIII, as might be concluded by using Figure 2 as a conversion mechanism.

The bottom line is that we either have to conclude that this upward shift in SFI relative to MMI is true, or that the scaling relationship included in the source model is flawed. We compared the scaling relative to the moment magnitude scaling in Boore, Joyner and Fumal (1993). The scaling factor being used is $0.5 \log M$, well within the range of 0.45 to $0.48 \log M$ for the frequency range of interest.

A valid question is "what impact does the change from the original model to the current model incorporating scaling and directivity have on the risk associated with the typical M=7 earthquake expected in the Bay Area?" Four changes should be examined.

1. MMI levels perpendicular to the fault trace do **drop faster** for a M=7 than a M=8+ earthquake, resulting in a decrease in damage potential, as shown in Figure B4.

2. However, the upward shift in the relationship of MMI to SFI results in anywhere from a half intensity increment **increase** in damage associated with SFI intensity, if one assumed a one-to-one correspondence (as favored by Perkins, 1978, and Perkins, 1992) or a full intensity increment increase, if one assumed a half intensity increment downward shift (as favored by Borchardt as early as 1975 but never published).
3. The levels of shaking along the fault axis are **dramatically increased** due to the effects of directivity previously discussed, as shown in Figure B5.
4. Because of the arbitrary scaling of M=7 earthquakes vs. M=8 earthquakes using a one intensity unit drop on the y-axis in earlier reports (see Laird, Perkins and others, 1978; Perkins, 1982; Perkins, 1987a; Perkins, 1987b), the levels of shaking depicted in this document are **larger** near the fault trace relative to these first generation models.

Thus, although at first glance it might seem that the scaling assumptions used in this report decrease the risk associated with the approximate M=7 earthquake scenarios, the mapped risk is actually increased significantly.

We do not believe that this "flexibility" in assignment of the model curve relative to the y-axis for 1989 causes a serious problem with our attempts to perform an error analysis of this model relative to the previous model. The principal reason the change to the revised model was its ability to depict striking directivity along the fault axis which is apparent even when the impacts of the Moho are incorporated into the effort.

However, the scaling of the model cannot be adequately tested when comparing just the 1906 San Francisco and 1989 Loma Prieta earthquakes. Thus, another earthquake was needed. The 1984 Morgan Hill earthquake was used for this crucial test. As the scaling currently stands, the model slightly over predicts the damage associated with this earthquake. If one flattens the slope of the scaling relationship, this over prediction will increase.

There was also the potential that the transfer from SFI to MMI would require changing the shape of the curve (that is, making it steeper or flatter) to account for a non-linear correspondence between the two scales.

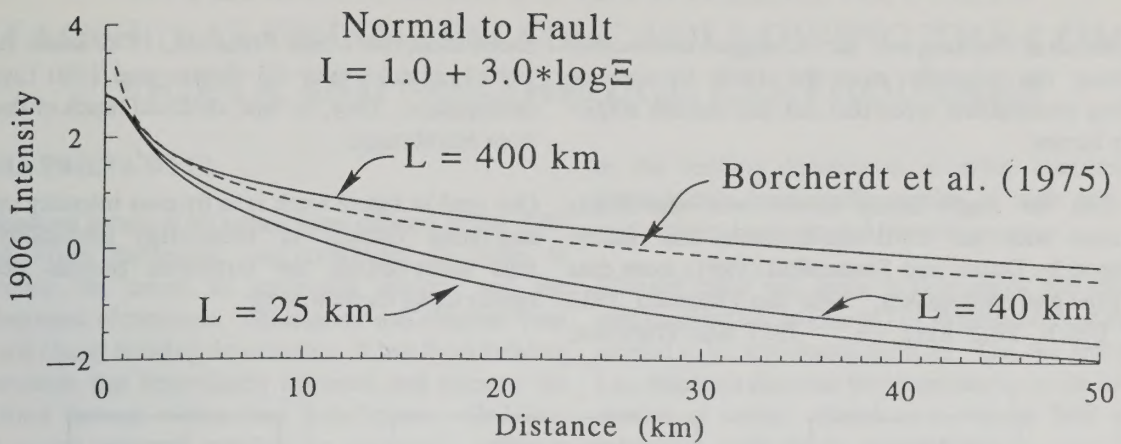


FIGURE B3 -- The attenuation normal to the fault for three different rupture lengths ($L = 200$, 40 , and 25 km). These rupture lengths correspond roughly to the 1906 San Francisco earthquake, the 1989 Loma Prieta earthquake, and the 1984 Morgan Hill earthquake. The dashed line shows the fit obtained by Borchardt et al. (1975) to the 1906 intensities. The smaller the fault length, the more rapidly the intensity attenuates away from the fault.

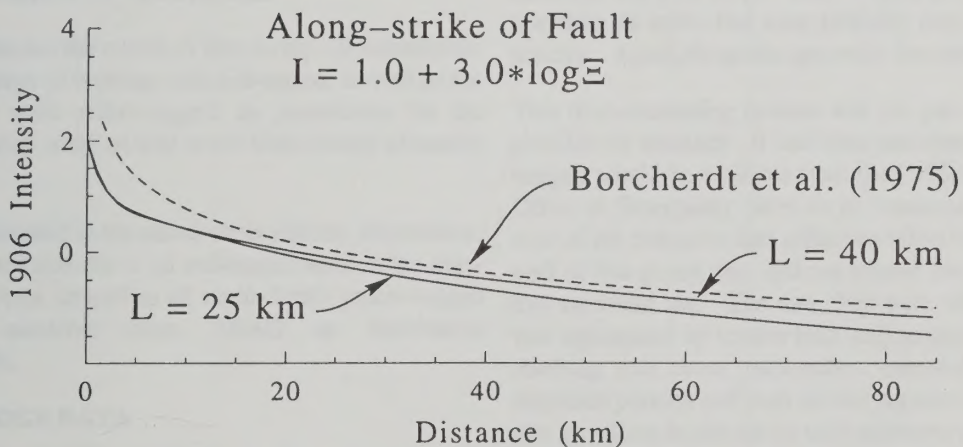


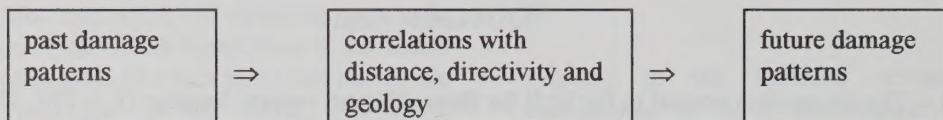
FIGURE B4 -- The attenuation along the fault for two different rupture lengths ($L = 40$ and 25 km). The dashed line shows the fit obtained by Borchardt et al. (1975) to the 1906 intensities normal to the San Andreas fault. The attenuation of intensity as a function of distance along strike of the fault does not depend strongly on the fault length.

The process of "backing out" the red-tagged matrix after finalizing the intensity map for 1989 focused on building construction types that did not include single-family homes.

The data for single-family homes was remarkably consistent with the MMI/uninhabitable unit matrix developed by Dunne and Sonnenfeld (1991) from data from nine past earthquakes: 1906 San Francisco, 1933 Long Beach, 1952 Kern Co., 1957 San Francisco, 1969

Santa Rosa, 1971 San Fernando, 1978 Santa Barbara, 1979 Imperial Valley /El Centro, and 1980 Livermore earthquakes. They, in turn, obtained much of their data from Steinbrugge.

Our goal in future work is to by-pass intensity mapping and create "damage" or "habitability" probability maps, thus short-cutting the circuitous process described earlier using the following:



This area of research deserves extensive additional effort to confirm the relationships proposed here. In spite of the importance of the results of this research, we have only looked at four past earthquakes, to date.

APPENDIX C -- DATA ON DWELLING UNITS TAGGED AS UNINHABITABLE FOLLOWING THE LOMA PRIETA AND NORTHRIDGE EARTHQUAKES

LOMA PRIETA DATA

A telephone survey of all jurisdictions affected by the 1989 Loma Prieta earthquake was conducted in order to determine the extent of residential damage and the displacement of residents. Information was obtained from city and county building departments. It was these building departments that immediately inspected and assessed the structural damage within their jurisdictions. Buildings were tagged with red = unsafe for occupancy, yellow = limited access and green = safe. Survey respondents were asked to identify the residential red and yellow tagged buildings within their jurisdictions, as well as structure type and street address. Not all departments with "red-tagged" buildings could provide addresses.

One problem with getting the information was that some cities kept incomplete or no records of their tagging. Some cities had extensive records, but these were not organized in any intelligible manner. Other jurisdictions summarized their inspections very early on, so that their summary of total red-tagged units may be a low estimate relative to the actual "red-tagged" count (such as may have been the case in Gilroy and San Jose). Many building departments discovered new quake damage long after the earthquake as homeowners applied for repair permits.

Table C1 contains the results of that survey. It summarizes the total number of housing units red-tagged, as well as the multi-family units yellow-tagged, by jurisdiction for the nine-county Bay Area, as well as the three-county Monterey Bay Area.

For those interested in the actual street address information, a PC-formatted diskette of all red-tagged units in the nine-county Bay Area, as well as all multi-family yellow-tagged units, is available from ABAG as Publication P960001EQK.

NORTHRIDGE DATA

In an attempt to duplicate the process of collecting data on red- and yellow-tagged residential buildings following the Loma Prieta earthquake for the Los Angeles and Ventura county areas, ABAG project staff conducted a telephone survey of the affected city and county building departments. This interview effort was supplemented by approximately 20 person-days in the impacted area to check data supplied

by the building departments to ensure consistency, add missing data (particularly number of units and age for multi-family housing), and improve accuracy.

Minimal effort was made to field check and supplement data supplied by the City of Los Angeles because these data seemed to be remarkably accurate. The one problem with Los Angeles's data was the inconsistency in the labeling of number of stories. Based on a two-day field survey of residential multi-family buildings in the San Fernando Valley, staff estimated that approximately half of the units described as being in three-story structures were actually in three-story structures over a one-story parking garage (which, for purposes of this effort, should have been labeled as four-story structures). Rather than arbitrarily re-categorizing half of these structures as four-story buildings, we used available data on year built, number of units, construction type and square footage to assign the specific structures most likely to be four-story buildings to the four-story category. Approximately half of the total units in three-story buildings were reassigned to four-story buildings. Because we carefully documented the specific buildings involved, we will be able to field check these buildings as part of future data collection efforts. In addition, a few obvious inconsistencies in the data were corrected (such as a "26" story wood-frame building with less than six units) that were probably data entry errors by the city. Again, these changes were documented.

This time-consuming process was not part of the original plan for the research. It had been anticipated that data on tagging would be available from the California Governor's Office of Emergency Services in Pasadena. However, in spite of the extensive data collection effort conducted by the staff of this group, they did not release the data in a form that we could use. The data they were willing to release was aggregated by census tract and stripped of the actual dwelling unit count information essential to estimating displaced persons and peak shelter populations. They were also unwilling to provide us with addresses so that we could collect the dwelling unit data needed and add it to their data base, in part due to concerns expressed by many of the cities that supplied the tagging data.

Table C2 shows ABAG data collected for housing impact analysis. It compares data collected by ABAG to two sources of data supplied by the OES Pasadena group -- the first was a FAX dated 2-7-95; the second was a report (EQE and OES, April 1995).

**TABLE C1 – RESULTS OF ABAG SURVEY CONDUCTED IN 1994 OF CITIES AND COUNTIES
RELATED TO URMS AND HOUSING DAMAGE IN THE LOMA PRIETA EARTHQUAKE**

County	City	No. of URMs	No. of Historic URMs	No. of Residential URMs	No. of Units within Residential URMs	No. of Yellow- Tagged Residential Units	No. of Yellow- Tagged Residential Buildings	No. of Red- Tagged Residential Units	No. of Red- Tagged Residential Buildings
Alameda County	Alameda	82	7	9	64	0	0	0	0
Alameda County	Albany	58	0	1	46	0	0	0	0
Alameda County	Berkeley	444	0	41	897	150	150	45	3
Alameda County	Dublin	0	0	0	0	0	0	0	0
Alameda County	Emeryville	101	1	41	100	35	35	2	1
Alameda County	Fremont	32	5	5	14	50	50	0	0
Alameda County	Hayward	49	49	1	40	10	10	0	0
Alameda County	Livermore	48	3	1	1	0	0	0	0
Alameda County	Newark	0	0	0	0	0	0	0	0
Alameda County	Oakland	1666	120	153	3264	2008	199	1349	87
Alameda County	Piedmont	0	0	0	0	0	0	0	0
Alameda County	Pleasanton	36	0	0	0	0	0	0	0
Alameda County	San Leandro	59	0	1	24	1	1	0	0
Alameda County	Union City	7	0	0	0	0	0	0	0
Alameda County	Unincorporated	18	0	0	0	0	0	0	0
Contra Costa Co	Antioch	64	0	8	21	0	0	0	0
Contra Costa Co	Brentwood	7	0	0	0	0	0	0	0
Contra Costa Co	Clayton	0	0	0	0	0	0	0	0
Contra Costa Co	Concord	9	2	0	0	18	18	0	0
Contra Costa Co	Danville	5	4	0	0	16	16	0	0
Contra Costa Co	El Cerrito	32	0	0	0	0	0	0	0
Contra Costa Co	Hercules	3	2	0	0	0	0	0	0
Contra Costa Co	Lafayette	0	0	0	0	0	0	0	0
Contra Costa Co	Martinez	58	0	0	0	0	0	0	0
Contra Costa Co	Moraga	0	0	0	0	0	0	0	0
Contra Costa Co	Orinda	0	0	0	0	0	0	0	0
Contra Costa Co	Pinole	10	2	0	0	0	0	0	0
Contra Costa Co	Pittsburg	24	16	0	0	0	0	0	0
Contra Costa Co	Pleasant Hill	0	0	0	0	0	0	0	0
Contra Costa Co	Richmond	70	5	14	104	0	0	0	0
Contra Costa Co	San Pablo	0	0	0	0	0	0	0	0
Contra Costa Co	San Ramon	0	0	0	0	0	0	0	0
Contra Costa Co	Walnut Creek	12	0	1	4	0	0	0	0
Contra Costa Co	Unincorporated	66	0	19	42	12	12	0	0
Marin County	Belvedere	0	0	0	0	0	0	0	0
Marin County	Corte Madera	4	0	0	0	0	0	0	0
Marin County	Fairfax	4	0	3	15	0	0	0	0
Marin County	Larkspur	8	0	1	1	1	1	0	0
Marin County	Mill Valley	18	0	0	0	0	0	0	0
Marin County	Novato	2	0	0	0	0	0	0	0
Marin County	Ross	1	0	0	0	0	0	0	0
Marin County	San Anselmo	22	1	4	6	0	0	0	0
Marin County	San Rafael	50	0	17	109	1	1	0	0
Marin County	Sausalito	10	7	5	16	0	0	0	0
Marin County	Tiburon	1	0	0	0	0	0	0	0
Marin County	Unincorporated	1	0	0	0	0	0	2	2

**TABLE C1 – RESULTS OF ABAG SURVEY CONDUCTED IN 1994 OF CITIES AND COUNTIES
RELATED TO URMS AND HOUSING DAMAGE IN THE LOMA PRIETA EARTHQUAKE (CONT.)**

County	City	No. of URMs	No. of Historic URMs	No. of Residential URMs	No. of Units within Residential URMs	No. of Yellow- Tagged Residential Units	No. of Yellow- Tagged Residential Buildings	No. of Red- Tagged Residential Units	No. of Red- Tagged Residential Buildings
Napa County	American Canyon	0	0	0	0	0	0	0	0
Napa County	Calistoga	30	0	0	0	0	0	0	0
Napa County	Napa	45	12	0	0	0	0	0	0
Napa County	Saint Helena	27	27	1	1	0	0	0	0
Napa County	Yountville	9	3	0	0	0	0	0	0
Napa County	Unincorporated	7	5	0	0	0	0	0	0
San Francisco	San Francisco	2080	1400	628	18921	7318	759	2078	215
San Mateo Co	Atherton	1	1	0	0	0	0	0	0
San Mateo Co	Belmont	4	0	1	4	0	0	0	0
San Mateo Co	Brisbane	4	0	0	0	0	0	0	0
San Mateo Co	Burlingame	63	0	4	13	0	0	0	0
San Mateo Co	Colma	4	0	0	0	0	0	0	0
San Mateo Co	Daly City	1	0	1	3	20	20	0	0
San Mateo Co	East Palo Alto	0	0	0	0	0	0	0	0
San Mateo Co	Foster City	0	0	0	0	0	0	0	0
San Mateo Co	Half Moon Bay	2	1	0	0	26	26	0	0
San Mateo Co	Hillsborough	0	0	0	0	0	0	0	0
San Mateo Co	Menlo Park	2	0	0	0	0	0	0	0
San Mateo Co	Millbrae	2	0	0	0	150	150	0	0
San Mateo Co	Pacifica	0	0	0	0	3	3	0	0
San Mateo Co	Portola Valley	0	0	0	0	0	0	0	0
San Mateo Co	Redwood City	33	4	1	53	0	0	53	1
San Mateo Co	San Bruno	5	0	0	0	0	0	1	1
San Mateo Co	San Carlos	10	2	3	4	25	25	1	1
San Mateo Co	San Mateo	28	0	3	71	300	300	1	1
San Mateo Co	So. San Francisco	23	3	4	4	42	42	12	2
San Mateo Co	Woodside	0	0	0	0	0	0	0	0
San Mateo Co	Unincorporated	7	4	0	0	32	32	8	8
Santa Clara Co	Campbell	11	4	0	0	36	36	1	1
Santa Clara Co	Cupertino	1	0	0	0	50	50	0	0
Santa Clara Co	Gilroy	35	0	2	2	350	350	52	52
Santa Clara Co	Los Altos	1	0	0	0	1	1	1	1
Santa Clara Co	Los Altos Hills	0	0	0	0	65	65	10	10
Santa Clara Co	Los Gatos	21	6	2	21	500	500	25	24
Santa Clara Co	Milpitas	1	0	1	1	5	5	0	0
Santa Clara Co	Monte Sereno	0	0	0	0	0	0	1	1
Santa Clara Co	Morgan Hill	7	2	0	0	1	1	43	43
Santa Clara Co	Mountain View	25	7	2	24	0	0	46	11
Santa Clara Co	Palo Alto	49	0	1	26	0	0	2	1
Santa Clara Co	San Jose	196	0	0	0	18	18	8	8
Santa Clara Co	Santa Clara	24	0	0	0	0	0	0	0
Santa Clara Co	Saratoga	0	0	0	0	0	0	6	6
Santa Clara Co	Sunnyvale	86	30	0	0	10	10	3	3
Santa Clara Co	Unincorporated	14	0	0	0	303	303	210	208

**TABLE C1 – RESULTS OF ABAG SURVEY CONDUCTED IN 1994 OF CITIES AND COUNTIES
RELATED TO URMS AND HOUSING DAMAGE IN THE LOMA PRIETA EARTHQUAKE (CONT.)**

County	City	No. of URMs	No. of Historic URMs	No. of Residential URMs	No. of Units within Residential URMs	No. of Yellow- Tagged Residential Units	No. of Yellow- Tagged Residential Buildings	No. of Red- Tagged Residential Units	No. of Red- Tagged Residential Buildings
Solano County	Benicia	39	18	0	0	0	0	0	0
Solano County	Dixon	12	0	0	0	0	0	0	0
Solano County	Fairfield	4	0	0	0	0	0	0	0
Solano County	Rio Vista	10	0	0	0	0	0	0	0
Solano County	Suisun City	24	0	0	0	0	0	0	0
Solano County	Vacaville	20	7	0	0	0	0	0	0
Solano County	Vallejo	64	8	6	56	2	2	0	0
Solano County	Unincorporated	2	0	0	0	0	0	0	0
Sonoma County	Cloverdale	18	2	0	0	0	0	0	0
Sonoma County	Cotati	0	0	0	0	0	0	0	0
Sonoma County	Healdsburg	18	0	2	5	0	0	0	0
Sonoma County	Petaluma	90	32	1	1	0	0	0	0
Sonoma County	Rohnert Park	0	0	0	0	0	0	0	0
Sonoma County	Santa Rosa	68	0	2	4	5	5	0	0
Sonoma County	Sebastopol	30	0	2	6	0	0	0	0
Sonoma County	Sonoma	51	29	3	19	0	0	0	0
Sonoma County	Windsor	0	0	0	0	0	0	0	0
Sonoma County	Unincorporated	174	16	7	28	0	0	0	0
Monterey	Carmel	22	0	0	0	0	0	0	0
Monterey	Del Rey Oaks	0	0	0	0	0	0	0	0
Monterey	Gonzales	3	1	0	0	1	1	0	0
Monterey	Greenfield	7	0	1	4	0	0	0	0
Monterey	King City	7	0	0	0	0	0	0	0
Monterey	Marina	0	0	0	0	0	0	0	0
Monterey	Monterey	60	0	6	30	0	0	0	0
Monterey	Pacific Grove	9	6	0	0	0	0	0	0
Monterey	Salinas	70	0	0	0	200	200	12	12
Monterey	Sand City	0	0	0	0	0	0	0	0
Monterey	Seaside	13	1	0	0	0	0	2	2
Monterey	Soledad	4	0	0	0	0	0	1	1
Monterey	Unincorporated	0	0	0	0	20	20	10	10
San Benito	Hollister	3	0	0	0	48	48	63	63
San Benito	San Juan Bautista	28	0	20	0	0	0	0	0
San Benito	Unincorporated	0	0	0	0	80	80	12	12
Santa Cruz	Santa Cruz	46	24	1	1	372	372	72	72
Santa Cruz	Capitola	1	0	0	0	0	0	6	6
Santa Cruz	Scotts Valley	0	0	0	0	160	160	11	11
Santa Cruz	Watsonville	72	1	0	0	200	200	275	275
Santa Cruz	Unincorporated	11	0	0	0	3717	3717	2619	2619
TOTALS		6919	1880	1030	24070	16362	7994	7043	3774

TABLE C2 – NORTHRIDGE EARTHQUAKE RESIDENTIAL TAGGING DATA

[Data from ABAG survey compared with OES FAX (2-7-95) and OES report (EQE and OES, April 1995)]

City	Red-Tagged Residential								
	ABAG							OES (FAX)	EQE/OES
	Residential Buildings	Single Family	Multi-Family	Total Units in Buildings	Mobile Homes	Total Residential Units	Residential Buildings	Residential Buildings	(Report) Residential Buildings
			Buildings	Units					
Beverly Hills	18	12	6	130	142	0	142	22	21
Burbank	12	8	4	47	55	0	55	30	3
Calabasas	10	5	5	44	49	0	49	0	0
Culver City	20	19	1	2	21	0	21	14	15
Glendale	6	4	2	64	68	0	68	10	17
Los Angeles	1300	781	519	11358	12139	2083	14222	1519	1604
Manhattan Beach	2	2	0	0	2	0	2	3	0
Pasadena	1	0	1	12	12	0	12	4	5
San Fernando	99	52	47	170	222	105	327	82	27
Santa Clarita	80	64	16	184	248	1606	1854	60	83
Santa Monica	27	12	15	301	313	0	313	60	67
West Hollywood	3	0	3	13	13	0	13	3	4
Unincorporated	46	44	2	7	51	193	244	0	28
Fillmore	120	117	3	12	129	86	215	0	144
Moorpark	1	1	0	0	1	3	4	0	2
Simi Valley	13	9	4	22	31	519	550	0	25
Thousand Oaks	53	47	6	18	65	0	65	0	55
Unincorporated	14	14	0	0	14	0	14	0	14
TOTALS	1,825	1,191	634	12,384	13,575	4,595	18,170	1,807	2,114

City	Yellow-Tagged Residential								
	ABAG							OES (FAX)	EQE/OES
	Residential Buildings	Single Family	Multi-Family	Total Units in Buildings	Mobile Homes	Total Residential Units	Residential Buildings	Residential Buildings	(Report) Residential Buildings
			Buildings	Units					
Beverly Hills	84	68	16	95	163	0	163	80	53
Burbank	31	24	7	80	104	0	104	71	7
Calabasas	233	222	11	59	281	0	281	220	0
Culver City	46	43	3	6	49	0	49	10	12
Glendale	2	1	1	167	168	0	168	11	9
Los Angeles	7214	5359	1855	27856	33215	1033	34248	7340	7715
Manhattan Beach	272	268	4	8	276	0	276	242	0
Pasadena	15	2	13	179	181	0	181	13	13
San Fernando	137	93	44	195	288	64	352	113	117
Santa Clarita	188	163	25	226	389	0	389	150	184
Santa Monica	91	28	63	890	918	0	918	212	239
West Hollywood	1	1	0	0	1	0	1	5	8
Unincorporated	201	159	42	639	798	15	813	0	85
Fillmore	263	254	9	27	281	0	281	0	228
Moorpark	59	59	0	0	59	0	59	0	22
Simi Valley	203	171	32	96	267	50	317	0	299
Thousand Oaks	213	205	8	29	234	0	226	0	121
Unincorporated	37	36	1	3	39	0	39	0	47
TOTALS	9,290	7,156	2,134	30,555	37,711	1162	38,873	8,467	9,159

APPENDIX D -- SUPPLEMENTAL INFORMATION ON THE DEVELOPMENT OF ESTIMATES OF EXPECTED PERCENTAGES OF RED- AND YELLOW-TAGGED UNITS BY INTENSITY LEVEL USED TO MODEL UNINHABITABLE HOUSING UNITS

INTRODUCTION

As stated in the body of this report, there are five major components in the model which develops estimates of uninhabitable housing units:

1. intensity mapping;
2. land use mapping;
3. TIGER file maps of census tracts and cities;
4. residential building stock; and
5. the red- and yellow-matrices relating intensity exposure and residential construction type to percentages of units made uninhabitable.

Of these five components, the (5) matrices are second only to intensity mapping in their lack of precision and their potential to greatly under- or over-estimate uninhabitable housing in future earthquakes.

The procedure used to develop these matrices involved the analysis and integration of three separate data sources, each with its own set of strengths and weaknesses:

1. Loma Prieta data;
2. Northridge data; and
3. a set of matrices developed in the late 1970s for use in a similar housing impact analysis (Dunne and Sonnenfeld, 1991) (see Table D1).

LOMA PRIETA DATA

Data on red- and yellow-tagged units (except yellow-tagged single family homes) from the Loma Prieta earthquake were collected as described in Appendix C. These data were used with the Dunne and Sonnenfeld matrices to fine-tune the intensity model. However, in this later phase of research, these data were used with the modeled version of Loma Prieta shaking intensities in the reverse manner to create versions of red- and yellow-tagged matrices. In this process, data on number of units exposed and tagged were totaled, and the resulting percentages calculated.

Loma Prieta Data Strengths

- Because this earthquake affected many of the same buildings in Oakland and San Francisco

as anticipated future earthquakes, the idiosyncrasies of several uncommon construction types can be estimated.

- This earthquake was similar in size to anticipated future Bay Area earthquakes.

Loma Prieta Data Weaknesses

- Because these same data were used to generate the intensity models in the first place, the use of these data might be considered "redundant."
- The strongest shaking occurred in the Santa Cruz Mountains area of Santa Clara and Santa Cruz counties. Only minimal data (that are of no use in this particular phase of this effort) were able to be collected for Santa Cruz County. The housing which was most shaken (due to proximity to the earthquake fault source) was generally limited to pre-1940 single-family homes of a quality considered "poor" even when originally built (largely as second homes). The "mobile homes" are also not typical, being closer to RVs or campers, rather than the type of units described in Appendix A.

NORTHRIDGE DATA

Data from Loma Prieta indicated that post-1939 single family homes tend to be more likely to be habitable than indicated by the Dunne and Sonnenfeld matrices. The percentages derived for this building type were used to calculate a damage-based intensity value for each census tract in Los Angeles and Ventura counties. These "intensity" values were used to derive the remainder of the red- and yellow-tagged matrices. Again, in this process, data on number of units exposed and tagged were totaled, and the resulting percentages calculated.

Northridge Data Strengths

- This earthquake affected a modern residential area with construction almost identical to that expected to be affected in much of the suburban and newer urban Bay Area.

- This earthquake shook a huge number of housing units, causing an unprecedented impact on typical California housing stock.

Northridge Data Weaknesses

- This earthquake occurred on a thrust fault, causing directivity effects that are much more pronounced than in the Loma Prieta event. The intensity model used to re-create the Loma Prieta earthquake was unable to be easily modified to apply to this type of earthquake. Such a modification is a significant research effort beyond the scope of this project. Therefore, the data on tagged housing had to be correlated with itself (in this case, post-1939 single family homes) rather than with modeled intensity.
- As a consequence of the correlation process, only census tracts which contained red-tagged single family homes *and* one or more units of a second construction type could be used in creating the portion of the matrix relating to that second construction type. Thus, only a small percentage of the available data could be used. *It should be a high priority of future ABAG research to recreate an intensity model for the Northridge earthquake so that all the available data can be accessed.*

DUNNE AND SONNENFELD MATRIX

Prior to ABAG's work on housing habitability (Perkins, 1992), the only published matrix for relating these variables was developed by Dunne and Sonnenfeld (1991). Although the numbers in the matrix they developed were called "uninhabitable," there were no direct data on habitability since the data collection effort pre-dated the institutionalization of tagging by local building departments following damaging earthquakes. Rather, the results are based on insurance data from Karl Steinbrugge and use a damage threshold of approximately 20% as equivalent to "uninhabitable."

Dunne and Sonnenfeld Data Strengths

- The data were compiled from nine past earthquakes: 1906 San Francisco, 1933 Long Beach, 1952 Kern County, 1957 San Francisco, 1969 Santa Rosa, 1971 San Fernando, 1978 Santa Barbara, 1979 Imperial Valley/El Centro, and 1980 Livermore earthquakes.
- The amount of data, particularly on single family homes, is large.

**TABLE D1 – ESTIMATED PERCENT OF DWELLING UNITS MADE UNINHABITABLE
BY MODIFIED MERCALLI INTENSITY LEVEL**
[Source: Dunne and Sonnenfeld, 1991]

TYPE	MODIFIED MERCALLI INTENSITY					
	V	VI	VII	VIII	IX	X
Mobile Home	0.2	2.0	2.5	65.	90	100
Suspicious Masonry	0	0.3	8.0	45.	70	80
>13 Stories	0	0.2	2.5	9.0	17	20
<1940 Wood (SF)	0	0	0.11	3.0	14	20
<1940 Wood (MF)	0	0	0.34	9.0	37	54
>1940 Wood (SF)	0	0	0	0.18	4.2	10
>1940 Wood (MF)	0	0	0.02	3.0	21	35
>1940 Concrete and Steel	0	0	0.28	16.	54	70

Dunne and Sonnenfeld Data Weaknesses

- The data are based on damage, which though related to habitability, is not identical to it.
- The residential construction classification scheme used is not identical to that being used in this work, although many correlations can be easily applied.
- The data do not include the Loma Prieta and Northridge earthquakes, which affect a building stock more “modern” than some of the events examined. One might expect the data to be less accurate for post-1939 construction than pre-1940 construction.

PROCEDURE USED IN COMPILING “FINAL” RED-TAGGED MATRIX

In general, the Northridge data and Loma Prieta data were combined into a single matrix, summing the totals of the units red-tagged and the exposures to create a “combined” matrix. This combined data tended to be more statistically significant (due to the use of more total units) and to give less credence to “local” conditions. For example, in the Loma Prieta earthquake, homes built prior to 1940 in the Santa Cruz Mountains were heavily damaged in part due to their sub-standard construction as “second homes”, even by the standards for the era in which they were built. On the other hand, pre-1940 homes, by definition, were in the San Fernando Valley in 1971 when the San Fernando earthquake occurred. Many homes of this vintage were damaged in that earlier earthquake and were either torn down or significantly retrofitted.

However, if the total units exposed to a given intensity for a specified building construction type was small (that is, less than 1000 housing units for mobile homes and the two single-family categories, or less than 5000 housing units for the multi-family categories), another technique was used. For several categories, the Dunne and Sonnenfeld matrix data were used to extrapolate for the highest intensities based on the lower intensities. This technique was used for estimating MMI X for the two post-1939 categories of multi-family wood-frame construction, as well as both MMI IX and X for pre-1940 single family homes and 1-3 story wood-frame multi-family. The Dunne and Sonnenfeld matrix values were used directly for mobile homes in MMI IX and X.

The Dunne and Sonnenfeld percentages for URM's were used to assign the percentages for MMI VIII, IX and X for two construction categories with insufficient data for these intensities -- URM's and pre-1940 wood-frame multi-family of 4 or more stories. The Dunne and Sonnenfeld percentages were used, rather than extrapolation, due to the lack of data for MMI VIII from Loma Prieta and Northridge.

In the case of both <40 non-wood 4-7 story and <40 non-wood 7+ story, the total number of exposures from the two earthquakes combined failed to reach the 5000 unit multi-family cut-off of “significance” for ANY intensity level. The only “real” data of any sort was for intensity VII, with a percent red-tagged of 19% for 4-7 story buildings and 13% for 7+ story buildings. The decision was made to use the Dunne and Sonnenfeld values for URM's as a surrogate for these building types because these values were higher than the other Dunne and Sonnenfeld curves for Intensity VII.

The problem with >40 non-wood 4-7 story and >40 non-wood 7+ story is similar to that described above, except in this case, the data were generally sufficient for MMI VI and VII, with a percent red-tagged of 0%. The decision was made to use the Dunne and Sonnenfeld values for >1940 Concrete and Steel for these building types for MMI VIII, IX and X. This case and the previous case serve to reinforce the difficulty of overly subdividing non-wood frame residential buildings by construction category.

PROCEDURE USED IN COMPILING “FINAL” YELLOW-TAGGED MATRIX

Large amounts of evidence indicates that yellow-tagged *single-family* homes tend to remain occupied and are “habitable.” In addition, the equivalent of yellow-tagging for mobile homes, being classified as “damaged” as opposed to “fallen,” also meant that the homes could be occupied. Thus, the value for yellow-tagging in these three categories was “zero” because these units do not contribute to the uninhabitable housing stock.

The data on yellow tags was much more poorly defined than for red tags, in part due to the need to rely completely on data from Northridge and Loma Prieta. However, whenever feasible, it was used.

For pre-1940 non-wood construction in MMI V-VIII, as well as for post-1940 non-wood construction

and pre-1940 4+ story wood construction in MMI VIII - X, the difference between the percent red tagged for given intensity level and the next higher intensity level was used to estimate the percent yellow tagged. Thus, if red tagging for MMI VIII were 8 percent, and for MMI VII were 0.3 percent, the yellow tagging for MMI VII was assumed to be $8 - 0.3 = 7.7$ percent. This system was also used for pre-1940 wood 1-3 story multi-family construction in MMI IX and X. For these, as well as MMI X for post-1939 wood 4+ story construction, MMI X was assumed to be equal to MMI IX. This technique is probably not very accurate, and should be replaced by "real" data when available.

Finally, although little data were available, there is some indication that the sum of yellow- and red-tagged units in MMI IX and X for unreinforced masonry, as well as both categories of pre-1940 non-wood construction, approaches 100 percent. The yellow-tagged values were assigned so that the sum of yellow- and red-tagged values would equal 100 percent.

SIGNIFICANT CHANGES FROM DUNNE AND SONNENFELD DATA

The most significant improvements of these matrices on the Dunne and Sonnenfeld data are related to the recognition that

- habitability has only a limited relationship with dollar loss or percent damage; and

- multi-family housing is almost always uninhabitable if yellow-tagged as limited entry, whereas single family housing is almost always able to be occupied if yellow-tagged.

The categories of construction with the greatest discrepancies from the Dunne and Sonnenfeld matrices (if those matrices are equated to red-tagging, rather than habitability) are:

- a huge reduction in the percentages of red-tagged post-1939 single family homes relative to the other construction categories;
- a decrease in mobile home percentages for MMI V, VI and VII;
- a four-fold increase in the percentage for MMI VIII for post-1939 1-3 story wood-frame apartments;
- an almost six-fold increase in the percentages for MMI VIII for post-1939 4+ story wood-frame apartments;
- a significant increase across most intensities for pre-1940 4 or more story wood-frame apartments (exposed to high intensities for the first time in Loma Prieta);
- a decrease in the percentages of MMI VI and VII for unreinforced masonry buildings.

APPENDIX E --

THE PEAK SHELTER POPULATION MODEL

BACKGROUND

The Peak Shelter Population Model blends expert opinion, actual demographic data, and output from the ABAG damage model to determine the number of persons who will seek public shelter following a bay area earthquake. The model calculates the expected peak shelter seeking population for each of the over 2,000 census tracts in the Bay Area. The extreme variations in demographic descriptions and in number of occupants per dwelling unit in the Bay area necessitated that the analysis be performed at the smallest geographical unit possible--the census tract. The results of these calculations are summed to give county and city peak shelter population predictions for each earthquake scenario.

Figure E1 shows the four level hierarchical multi attribute model that was used to calculate the probability that a household will seek shelter. This probability is multiplied by the number of households in the census tract and the average number of persons in a household in that tract to determine the number of people who will seek shelter. The upper level of the hierarchy is the probability that a dwelling will be damaged. This probability is obtained for each census tract from the ABAG damage prediction model described in this report. Only a portion of those affected by a natural disaster, however, actually seek public shelter. The second level of the hierarchy consists of three demographic variables (income, ethnicity, and residence type) that were selected as important predictors of shelter seeking behavior based on examination of case histories of earthquakes, hurricanes, and other disasters and on the results of interviews with Red Cross mass care and shelter managers. The third level of the hierarchy is the actual distribution of the of the population for the census tract for each demographic variable. The fourth level of the hierarchy (not shown in Figure E1) is a rating provided by sheltering experts that represents the probability that a family described by the damage condition and demographic variable will seek public shelter.

MULTI-ATTRIBUTE FORMULATION FOR DETERMINING THE NUMBER OF PEOPLE SEEKING SHELTER

The hierarchical model shown in Figure E1 can be expressed in mathematical form as follows:

$$N_S = N_{SR} + N_{SY} = (D_R)(F)P(S|R) + (D_Y)(F)P(S|Y)$$

Where $N_{SR, SY}$ are the number of people seeking shelter from red and yellow tag dwellings, $D_{R, Y}$ are ABAG estimates of dwelling units red or yellow tagged, F is the number of persons per dwelling unit and $P(S|R)$ = the probability that a family from a red tagged dwelling will seek shelter

$$\begin{aligned} &= W_{IR} \{ P(S|I_1, R) P(I_1) P(R) + P(S|I_2, R) P(I_2) P(R) + \\ &\quad P(S|I_3, R) P(I_3) P(R) + P(S|I_4, R) P(I_4) P(R) + \\ &\quad P(S|I_5, R) P(I_5) P(R) \} \\ &+ W_{ER} \{ P(S|E_1, R) P(E_1) P(R) + P(S|E_2, R) P(E_2) P(R) + \\ &\quad P(S|E_3, R) P(E_3) P(R) + P(S|E_4, R) P(E_4) P(R) \} \\ &+ W_{HR} \{ P(S|H_1, R) P(H_1) P(R) + P(S|H_2, R) P(H_2) P(R) \} \\ &\text{and } P(S|Y) \end{aligned}$$

= the probability that a family from a yellow tagged dwelling will seek shelter

$$\begin{aligned} &= W_{IY} \{ P(S|I_1, Y) P(I_1) P(Y) + P(S|I_2, Y) P(I_2) P(Y) + \\ &\quad P(S|I_3, Y) P(I_3) P(Y) + P(S|I_4, Y) P(I_4) P(Y) + \\ &\quad P(S|I_5, Y) P(I_5) P(Y) \} \\ &+ W_{EY} \{ P(S|E_1, Y) P(E_1) P(Y) + P(S|E_2, Y) P(E_2) P(Y) + \\ &\quad P(S|E_3, Y) P(E_3) P(Y) + P(S|E_4, Y) P(E_4) P(Y) \} \\ &+ W_{HY} \{ P(S|H_1, Y) P(H_1) P(Y) + P(S|H_2, Y) P(H_2) P(Y) \} \end{aligned}$$

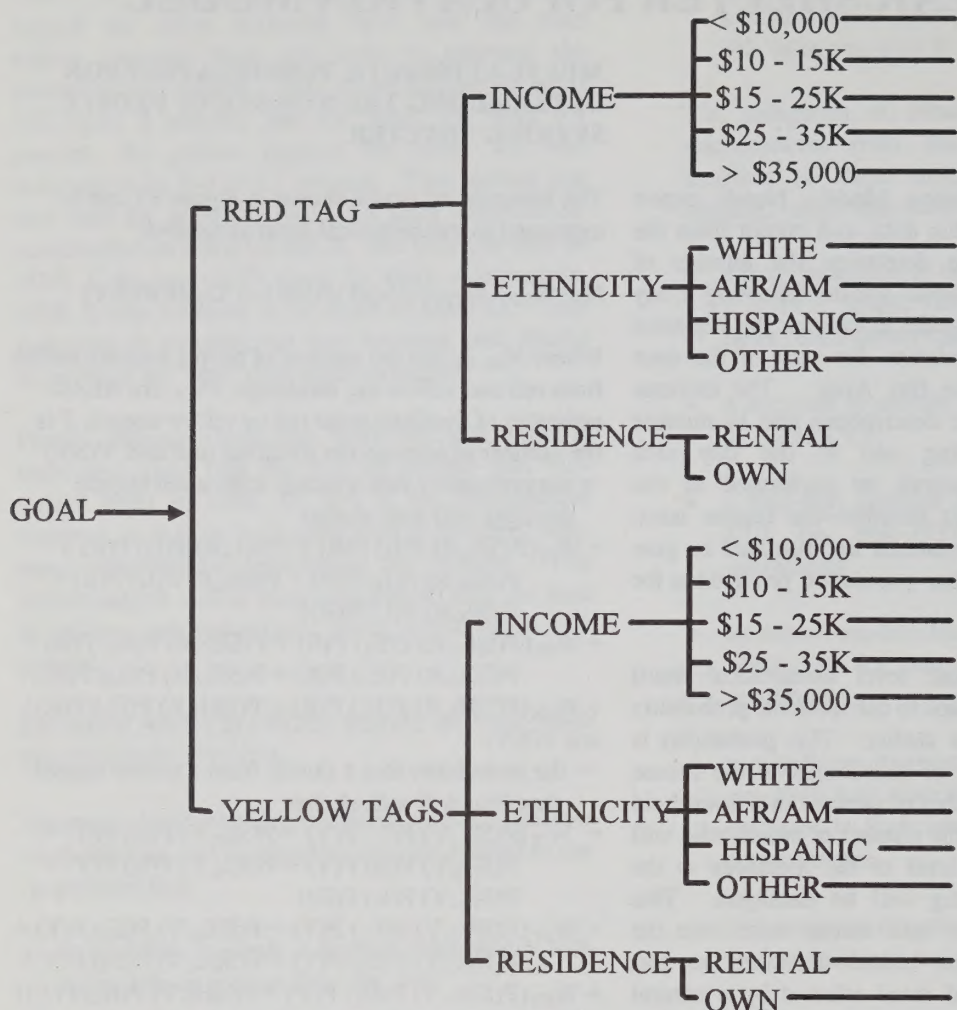
WHERE $P(R)$ and $P(Y)$ are the probability of a dwelling unit being red or yellow tagged and are obtained as output from the ABAG damage model for each of the earthquake scenarios.

AND $P(I_{1,2,3,4,5})$, $P(E_{1,2,3,4})$, $P(A_{1,2})$ AND $P(H_{1,2,3})$ are the probability of a family belonging to the income, ethnic, or housing category and are calculated from census data for each census tract.

AND conditional probabilities $P(S|I_i, R)$, $P(S|E_i, R)$, $P(S|H_i, R)$ represent the probability that a family will seek shelter given that their dwelling is red tagged and they are described by category I_i , E_i , H_i and were obtained from surveys of shelter experts, expert workshops, and a survey of Northridge earthquake victims.

AND the Weights W_{IR} , W_{ER} , W_{HR} , and W_{IY} , W_{EY} , W_{HY} were obtained from surveys of shelter experts, expert workshops, and a survey of Northridge earthquake victims.

FIGURE E1 -- THE PEAK SHELTER PREDICTION MODEL STRUCTURE



Goal: TO PREDICT THE PROBABILITY OF SEEKING SHELTER

Definitions:

\$10-15K	---	% Income level between \$10,000 and \$14,999	INCOME	---	Income distribution of households in affected area
\$15-25K	---	% Income level between \$15,000 and \$24,999	OTHER	---	% Other (ASIAN, NATIVE AMERICAN) Population
\$25-35K	---	% Income level between \$25,000 and \$34,999	OWN	---	% Owned residence
<\$10,000	---	% Income level below \$10,000	RED TAG	---	% of dwellings red tagged and uninhabitable
>\$35,000	---	% Income level over \$35,000	RENTAL	---	% Rental Residence
AFR/AM	---	% African American Population	RESIDENCE	---	Type of residence
ETHNIC	---	Ethnic distribution	WHITE	---	% White Non Hispanic Population
HISPANIC	---	% Hispanic Population	YELLOW TAG	---	% of Dwellings yellow tagged

APPENDIX F -- PREDICTED UNINHABITABLE DWELLING UNITS AND PEAK SHELTER POPULATIONS BY CITY

The following tables provide the red-tagged and yellow-tagged uninhabitable units, as well as the estimated peak shelter population associated with those units, by city.

The final column in each table is the estimated peak shelter population based on the number of people requiring shelter. Note that this peak shelter population is a minimum. Shelter providers should also understand that many people who are in undamaged or green-tagged units will seek public shelter. In the Northridge earthquake, these people were about half as many as those from uninhabitable units. Thus, you may want to increase the values by 50 percent. In addition, other factors, such as utility damage and fire following the earthquake may increase these numbers. Thus, you may want to even double these numbers. In addition, non-resident populations (such as tourists visiting San Francisco and commuters) are not directly included. Finally, shelter providers commonly have to house the entire pre-shelter homeless population.

TABLE F1 -- SAN ANDREAS PENINSULA SEGMENT EARTHQUAKE IMPACTS BY CITY

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
Alameda County	Alameda	465	657	1122	291	392	683
Alameda County	Albany	2	8	10	1	5	6
Alameda County	Berkeley	20	63	83	13	39	52
Alameda County	Dublin	0	0	0	0	0	0
Alameda County	Emeryville	160	280	439	85	142	227
Alameda County	Fremont	3	4	7	2	2	4
Alameda County	Hayward	20	5	25	15	4	19
Alameda County	Livermore	0	0	0	0	0	0
Alameda County	Newark	1	1	2	1	1	2
Alameda County	Oakland	371	915	1286	314	731	1045
Alameda County	Piedmont	1	0	1	0	0	0
Alameda County	Pleasanton	0	1	1	0	0	0
Alameda County	San Leandro	130	27	156	82	16	98
Alameda County	Union City	1	1	1	1	0	1
Alameda County	Unincorporated	2	3	5	1	1	2
Alameda County	Total	1175	1964	3139	806	1333	2139
Contra Costa Co	Antioch	0	1	2	0	1	1
Contra Costa Co	Brentwood	0	0	0	0	0	0
Contra Costa Co	Clayton	0	0	0	0	0	0
Contra Costa Co	Concord	0	1	1	0	1	1
Contra Costa Co	Danville	0	0	0	0	0	0
Contra Costa Co	El Cerrito	0	1	1	0	0	0
Contra Costa Co	Hercules	0	0	0	0	0	0
Contra Costa Co	Lafayette	0	0	0	0	0	0
Contra Costa Co	Martinez	0	0	1	0	0	0
Contra Costa Co	Moraga	0	0	0	0	0	0
Contra Costa Co	Orinda	0	0	0	0	0	0
Contra Costa Co	Pinole	0	0	0	0	0	0
Contra Costa Co	Pittsburg	0	1	1	0	0	0
Contra Costa Co	Pleasant Hill	0	1	1	0	0	0
Contra Costa Co	Richmond	16	18	34	13	14	27
Contra Costa Co	San Pablo	0	0	0	0	0	0
Contra Costa Co	San Ramon	0	0	0	0	0	0
Contra Costa Co	Walnut Creek	0	2	2	0	1	1
Contra Costa Co	Unincorporated	2	1	3	0	1	1
Contra Costa Co	Total	19	27	46	13	18	31
Marin County	Belvedere	7	7	14	3	3	6
Marin County	Corte Madera	2	4	6	1	2	3
Marin County	Fairfax	1	1	2	1	1	2
Marin County	Larkspur	16	7	23	17	7	24
Marin County	Mill Valley	19	15	34	14	10	24
Marin County	Novato	1	1	2	1	0	1
Marin County	Ross	0	0	0	0	0	0
Marin County	San Anselmo	0	0	0	0	0	0
Marin County	San Rafael	156	273	429	91	146	237
Marin County	Sausalito	62	73	135	39	42	81
Marin County	Tiburon	12	20	33	8	13	21
Marin County	Unincorporated	51	72	122	38	52	90
Marin County	Total	327	473	800	213	276	489
Napa County	American Canyon	0	0	0	0	0	0
Napa County	Calistoga	0	0	0	0	0	0
Napa County	Napa	1	1	2	0	1	1
Napa County	Saint Helena	0	0	0	0	0	0
Napa County	Yountville	0	0	0	0	0	0
Napa County	Unincorporated	1	0	0	0	0	0
Napa County	Total	1	1	2	0	1	1
San Francisco	San Francisco	7883	11350	19233	5425	7480	12905

TABLE F1 – SAN ANDREAS PENINSULA SEGMENT EARTHQUAKE IMPACTS BY CITY
(Cont.)

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
San Mateo Co	Atherton	13	2	15	7	1	8
San Mateo Co	Belmont	264	443	706	147	226	373
San Mateo Co	Brisbane	0	0	0	0	0	0
San Mateo Co	Burlingame	635	800	1435	341	406	747
San Mateo Co	Colma	1	0	1	0	0	0
San Mateo Co	Daly City	109	212	321	93	167	260
San Mateo Co	East Palo Alto	47	71	118	51	73	124
San Mateo Co	Foster City	212	361	573	116	175	291
San Mateo Co	Half Moon Bay	159	48	207	107	29	136
San Mateo Co	Hillsborough	41	2	43	23	1	24
San Mateo Co	Menlo Park	371	568	940	212	299	511
San Mateo Co	Millbrae	108	157	265	67	88	155
San Mateo Co	Pacifica	146	180	326	98	110	208
San Mateo Co	Portola Valley	64	33	97	34	14	48
San Mateo Co	Redwood City	1519	1105	2624	1014	691	1705
San Mateo Co	San Bruno	335	460	795	218	276	494
San Mateo Co	San Carlos	75	78	154	40	38	78
San Mateo Co	San Mateo	1414	2205	3619	854	1241	2095
San Mateo Co	So. San Francisco	120	175	295	93	124	217
San Mateo Co	Woodside	7	2	9	4	1	5
San Mateo Co	Unincorporated	438	201	639	331	164	495
San Mateo Co	Total	6066	7100	13166	3843	4123	7966
Santa Clara Co	Campbell	16	27	43	9	15	24
Santa Clara Co	Cupertino	84	127	211	47	63	110
Santa Clara Co	Gilroy	1	1	1	1	1	2
Santa Clara Co	Los Altos	68	74	142	36	32	68
Santa Clara Co	Los Altos Hills	8	1	8	4	0	4
Santa Clara Co	Los Gatos	99	84	182	54	41	95
Santa Clara Co	Milpitas	3	2	5	3	1	4
Santa Clara Co	Monte Sereno	4	0	5	2	0	2
Santa Clara Co	Morgan Hill	1	1	2	1	0	1
Santa Clara Co	Mountain View	868	1363	2232	508	762	1270
Santa Clara Co	Palo Alto	843	1192	2035	450	582	1032
Santa Clara Co	San Jose	442	580	1022	352	421	773
Santa Clara Co	Santa Clara	565	897	1462	363	540	903
Santa Clara Co	Saratoga	42	44	86	23	20	43
Santa Clara Co	Sunnyvale	916	826	1742	550	465	1015
Santa Clara Co	Unincorporated	105	53	158	68	33	101
Santa Clara Co	Total	4066	5270	9336	2471	2976	5447
Solano County	Benicia	0	0	0	0	0	0
Solano County	Dixon	0	0	0	0	0	0
Solano County	Fairfield	0	1	1	0	0	0
Solano County	Rio Vista	0	0	0	0	0	0
Solano County	Suisun City	0	0	0	0	0	0
Solano County	Vacaville	0	0	0	0	0	0
Solano County	Vallejo	2	7	9	1	5	6
Solano County	Unincorporated	0	0	0	0	0	0
Solano County	Total	2	8	10	1	5	6
Sonoma County	Cloverdale	0	0	0	0	0	0
Sonoma County	Cotati	0	0	0	0	0	0
Sonoma County	Healdsburg	0	0	0	0	0	0
Sonoma County	Petaluma	1	0	1	0	0	0
Sonoma County	Rohnert Park	0	1	1	0	0	0
Sonoma County	Santa Rosa	0	1	1	0	0	0
Sonoma County	Sebastopol	0	0	0	0	0	0
Sonoma County	Sonoma	0	0	0	0	0	0
Sonoma County	Windsor	0	0	0	0	0	0
Sonoma County	Unincorporated	0	1	1	0	0	0
Sonoma County	Total	1	3	4	0	0	0

TABLE F2 -- SAN GREGORIO EARTHQUAKE IMPACTS BY CITY

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
Alameda County	Alameda	306	491	797	192	293	485
Alameda County	Albany	2	8	10	1	5	6
Alameda County	Berkeley	20	63	82	13	39	52
Alameda County	Dublin	0	0	0	0	0	0
Alameda County	Emeryville	6	65	72	3	33	36
Alameda County	Fremont	1	4	5	1	2	3
Alameda County	Hayward	5	5	10	4	4	8
Alameda County	Livermore	0	0	0	0	0	0
Alameda County	Newark	0	0	0	0	0	0
Alameda County	Oakland	205	775	980	173	619	792
Alameda County	Piedmont	1	0	1	0	0	0
Alameda County	Pleasanton	0	1	1	0	0	0
Alameda County	San Leandro	7	8	14	4	4	8
Alameda County	Union City	0	0	0	0	0	0
Alameda County	Unincorporated	2	1	4	1	1	2
Alameda County	Total	555	1421	1976	392	1000	1392
Contra Costa Co	Antioch	0	1	2	0	1	1
Contra Costa Co	Brentwood	0	0	0	0	0	0
Contra Costa Co	Clayton	0	0	0	0	0	0
Contra Costa Co	Concord	0	1	1	0	1	1
Contra Costa Co	Danville	0	0	0	0	0	0
Contra Costa Co	El Cerrito	0	1	1	0	0	0
Contra Costa Co	Hercules	0	0	0	0	0	0
Contra Costa Co	Lafayette	0	0	0	0	0	0
Contra Costa Co	Martinez	0	0	1	0	0	0
Contra Costa Co	Moraga	0	0	0	0	0	0
Contra Costa Co	Orinda	0	0	0	0	0	0
Contra Costa Co	Pinole	0	0	0	0	0	0
Contra Costa Co	Pittsburg	0	1	1	0	0	0
Contra Costa Co	Pleasant Hill	0	1	1	0	0	0
Contra Costa Co	Richmond	6	11	17	5	9	14
Contra Costa Co	San Pablo	0	0	0	0	0	0
Contra Costa Co	San Ramon	0	0	0	0	0	0
Contra Costa Co	Walnut Creek	0	2	2	0	1	1
Contra Costa Co	Unincorporated	1	2	3	0	1	1
Contra Costa Co	Total	8	20	28	5	13	18
Marin County	Belvedere	7	7	14	3	3	6
Marin County	Corte Madera	2	4	6	1	2	3
Marin County	Fairfax	1	1	2	1	1	2
Marin County	Larkspur	16	7	23	17	7	24
Marin County	Mill Valley	19	15	34	14	10	24
Marin County	Novato	1	1	2	1	0	1
Marin County	Ross	0	0	0	0	0	0
Marin County	San Anselmo	0	0	0	0	0	0
Marin County	San Rafael	156	275	431	91	146	237
Marin County	Sausalito	62	73	135	39	42	81
Marin County	Tiburon	12	20	33	8	13	21
Marin County	Unincorporated	53	75	128	40	54	94
Marin County	Total	330	478	808	215	278	493
Napa County	American Canyon	0	0	0	0	0	0
Napa County	Calistoga	0	0	0	0	0	0
Napa County	Napa	1	1	2	0	1	1
Napa County	Saint Helena	0	0	0	0	0	0
Napa County	Yountville	0	0	0	0	0	0
Napa County	Unincorporated	1	0	0	0	0	0
Napa County	Total	1	1	2	0	1	1
San Francisco	San Francisco	3394	8255	11650	2336	5441	7777

TABLE F2 -- SAN GREGORIO EARTHQUAKE IMPACTS BY CITY (Cont.)

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
San Mateo Co	Atherton	1	0	1	0	0	0
San Mateo Co	Belmont	1	4	5	1	2	3
San Mateo Co	Brisbane	0	0	0	0	0	0
San Mateo Co	Burlingame	34	99	133	18	50	68
San Mateo Co	Colma	1	0	1	0	0	0
San Mateo Co	Daly City	17	73	90	14	58	72
San Mateo Co	East Palo Alto	1	2	3	1	2	3
San Mateo Co	Foster City	4	13	17	2	6	8
San Mateo Co	Half Moon Bay	70	24	93	47	14	61
San Mateo Co	Hillsborough	4	0	4	2	0	2
San Mateo Co	Menlo Park	4	11	15	2	6	8
San Mateo Co	Millbrae	2	11	13	1	6	7
San Mateo Co	Pacifica	151	185	336	102	113	215
San Mateo Co	Portola Valley	0	0	1	0	0	0
San Mateo Co	Redwood City	18	45	63	12	28	40
San Mateo Co	San Bruno	16	31	47	11	19	30
San Mateo Co	San Carlos	1	0	2	1	0	1
San Mateo Co	San Mateo	26	176	201	16	99	115
San Mateo Co	So. San Francisco	11	19	30	9	13	22
San Mateo Co	Woodside	0	0	0	0	0	0
San Mateo Co	Unincorporated	233	30	263	134	17	151
San Mateo Co	Total	594	723	1317	373	433	806
Santa Clara Co	Campbell	1	1	2	0	1	1
Santa Clara Co	Cupertino	0	1	1	0	0	0
Santa Clara Co	Gilroy	0	0	0	0	0	0
Santa Clara Co	Los Altos	0	0	1	0	0	0
Santa Clara Co	Los Altos Hills	0	0	0	0	0	0
Santa Clara Co	Los Gatos	0	1	1	0	0	0
Santa Clara Co	Milpitas	0	0	0	0	0	0
Santa Clara Co	Monte Sereno	0	0	0	0	0	0
Santa Clara Co	Morgan Hill	0	0	0	0	0	0
Santa Clara Co	Mountain View	9	26	35	5	15	20
Santa Clara Co	Palo Alto	31	136	166	16	66	82
Santa Clara Co	San Jose	13	31	44	10	22	32
Santa Clara Co	Santa Clara	8	15	23	5	9	14
Santa Clara Co	Saratoga	0	0	0	0	0	0
Santa Clara Co	Sunnyvale	34	14	48	20	8	28
Santa Clara Co	Unincorporated	1	2	3	0	0	0
Santa Clara Co	Total	96	228	324	56	121	177
Solano County	Benicia	0	0	0	0	0	0
Solano County	Dixon	0	0	0	0	0	0
Solano County	Fairfield	0	1	1	0	0	0
Solano County	Rio Vista	0	0	0	0	0	0
Solano County	Suisun City	0	0	0	0	0	0
Solano County	Vacaville	0	0	0	0	0	0
Solano County	Vallejo	2	7	9	1	5	6
Solano County	Unincorporated	0	0	0	0	0	0
Solano County	Total	2	8	10	1	5	6
Sonoma County	Cloverdale	0	0	0	0	0	0
Sonoma County	Cotati	0	0	0	0	0	0
Sonoma County	Healdsburg	0	0	0	0	0	0
Sonoma County	Petaluma	1	1	1	0	0	0
Sonoma County	Rohnert Park	0	1	1	0	0	0
Sonoma County	Santa Rosa	0	1	2	0	1	1
Sonoma County	Sebastopol	0	0	0	0	0	0
Sonoma County	Sonoma	0	0	0	0	0	0
Sonoma County	Windsor	0	0	0	0	0	0
Sonoma County	Unincorporated	1	1	2	0	0	0
Sonoma County	Total	2	4	6	0	1	1

TABLE F3 -- NORTHERN HAYWARD EARTHQUAKE IMPACTS BY CITY

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
Alameda County	Alameda	3809	2330	6138	2385	1389	3774
Alameda County	Albany	990	626	1616	619	374	993
Alameda County	Berkeley	8620	4428	13048	5597	2725	8322
Alameda County	Dublin	14	19	33	9	11	20
Alameda County	Emeryville	854	603	1457	456	307	763
Alameda County	Fremont	68	42	110	45	26	71
Alameda County	Hayward	1489	933	2422	1149	681	1830
Alameda County	Livermore	1	1	2	0	1	1
Alameda County	Newark	16	25	41	12	17	29
Alameda County	Oakland	19995	11910	31905	16904	9514	26418
Alameda County	Piedmont	221	13	235	125	6	131
Alameda County	Pleasanton	8	5	13	5	2	7
Alameda County	San Leandro	1763	1249	3012	1112	741	1853
Alameda County	Union City	36	46	83	31	36	67
Alameda County	Unincorporated	870	918	1788	601	613	1214
Alameda County	Total	38753	23148	61901	29050	16443	45493
Contra Costa Co	Antioch	0	2	2	0	1	1
Contra Costa Co	Brentwood	0	0	0	0	0	0
Contra Costa Co	Clayton	0	0	0	0	0	0
Contra Costa Co	Concord	11	11	23	8	7	15
Contra Costa Co	Danville	3	2	5	2	1	3
Contra Costa Co	El Cerrito	545	295	841	319	161	480
Contra Costa Co	Hercules	20	16	35	13	9	22
Contra Costa Co	Lafayette	22	34	56	12	17	29
Contra Costa Co	Martinez	6	7	13	3	4	7
Contra Costa Co	Moraga	12	11	23	7	5	12
Contra Costa Co	Orinda	14	14	27	7	6	13
Contra Costa Co	Pinole	177	68	245	115	40	155
Contra Costa Co	Pittsburg	1	1	1	0	1	1
Contra Costa Co	Pleasant Hill	4	4	8	2	2	4
Contra Costa Co	Richmond	2234	1477	3711	1862	1144	3006
Contra Costa Co	San Pablo	1134	392	1526	1060	347	1407
Contra Costa Co	San Ramon	4	2	5	2	1	3
Contra Costa Co	Walnut Creek	6	53	59	3	24	27
Contra Costa Co	Unincorporated	649	322	971	404	195	599
Contra Costa Co	Total	4842	2711	7552	3819	1965	5784
Marin County	Belvedere	7	7	14	3	3	6
Marin County	Corte Madera	9	11	19	5	6	11
Marin County	Fairfax	1	1	2	1	1	2
Marin County	Larkspur	64	21	84	67	20	87
Marin County	Mill Valley	20	15	36	14	10	24
Marin County	Novato	273	141	414	161	79	240
Marin County	Ross	0	0	0	0	0	0
Marin County	San Anselmo	1	0	1	1	0	1
Marin County	San Rafael	521	381	902	305	203	508
Marin County	Sausalito	62	73	135	39	42	81
Marin County	Tiburon	21	23	44	14	15	29
Marin County	Unincorporated	243	112	319	173	77	250
Marin County	Total	1222	785	2007	783	456	1239
Napa County	American Canyon	4	0	5	3	0	3
Napa County	Calistoga	0	0	0	0	0	0
Napa County	Napa	8	7	15	5	5	10
Napa County	Saint Helena	0	0	0	0	0	0
Napa County	Yountville	1	0	1	1	0	1
Napa County	Unincorporated	1	0	1	1	0	1
Napa County	Total	15	8	22	10	5	15
San Francisco	San Francisco	5936	9328	15264	4085	6148	10233

TABLE F3 -- NORTHERN HAYWARD EARTHQUAKE IMPACTS BY CITY (Cont.)

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
San Mateo Co	Atherton	0	0	0	0	0	0
San Mateo Co	Belmont	1	3	4	0	2	2
San Mateo Co	Brisbane	0	0	0	0	0	0
San Mateo Co	Burlingame	6	23	29	3	12	15
San Mateo Co	Colma	0	0	0	0	0	0
San Mateo Co	Daly City	2	15	17	2	12	14
San Mateo Co	East Palo Alto	3	10	13	3	11	14
San Mateo Co	Foster City	4	13	17	2	6	8
San Mateo Co	Half Moon Bay	0	0	0	0	0	0
San Mateo Co	Hillsborough	0	0	0	0	0	0
San Mateo Co	Menlo Park	2	3	5	1	1	2
San Mateo Co	Millbrae	0	1	1	0	0	0
San Mateo Co	Pacifica	0	2	2	0	1	1
San Mateo Co	Portola Valley	0	0	0	0	0	0
San Mateo Co	Redwood City	13	27	40	9	17	26
San Mateo Co	San Bruno	1	2	3	1	1	2
San Mateo Co	San Carlos	1	0	1	0	0	0
San Mateo Co	San Mateo	12	81	93	7	46	53
San Mateo Co	So. San Francisco	2	3	4	1	2	3
San Mateo Co	Woodside	0	0	0	0	0	0
San Mateo Co	Unincorporated	6	3	9	5	2	7
San Mateo Co	Total	52	185	237	34	113	147
Santa Clara Co	Campbell	1	1	2	0	1	1
Santa Clara Co	Cupertino	0	1	1	0	0	0
Santa Clara Co	Gilroy	0	1	1	0	0	0
Santa Clara Co	Los Altos	0	0	1	0	0	0
Santa Clara Co	Los Altos Hills	0	0	0	0	0	0
Santa Clara Co	Los Gatos	0	1	1	0	0	0
Santa Clara Co	Milpitas	5	2	7	4	1	5
Santa Clara Co	Monte Sereno	0	0	0	0	0	0
Santa Clara Co	Morgan Hill	0	0	0	0	0	0
Santa Clara Co	Mountain View	9	26	35	5	15	20
Santa Clara Co	Palo Alto	14	40	54	7	19	26
Santa Clara Co	San Jose	77	94	171	61	68	129
Santa Clara Co	Santa Clara	12	21	34	8	13	21
Santa Clara Co	Saratoga	0	0	0	0	0	0
Santa Clara Co	Sunnyvale	35	14	49	21	8	29
Santa Clara Co	Unincorporated	3	2	5	2	2	4
Santa Clara Co	Total	156	203	360	108	127	235
Solano County	Benicia	0	0	1	0	0	0
Solano County	Dixon	0	0	0	0	0	0
Solano County	Fairfield	1	1	2	0	1	1
Solano County	Rio Vista	0	0	0	0	0	0
Solano County	Suisun City	2	2	3	1	1	2
Solano County	Vacaville	0	0	1	0	0	0
Solano County	Vallejo	174	151	326	139	112	251
Solano County	Unincorporated	0	0	1	0	0	0
Solano County	Total	177	155	333	140	114	254
Sonoma County	Cloverdale	0	0	0	0	0	0
Sonoma County	Cotati	1	0	1	1	0	1
Sonoma County	Healdsburg	0	0	1	0	0	0
Sonoma County	Petaluma	60	24	84	39	14	53
Sonoma County	Rohnert Park	14	4	18	10	2	12
Sonoma County	Santa Rosa	3	4	7	2	2	4
Sonoma County	Sebastopol	0	1	1	0	0	0
Sonoma County	Sonoma	5	2	7	3	1	4
Sonoma County	Windsor	1	0	1	1	0	1
Sonoma County	Unincorporated	29	7	36	18	3	21
Sonoma County	Total	113	42	156	74	22	96

TABLE F4 – SOUTHERN HAYWARD EARTHQUAKE IMPACTS BY CITY

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
Alameda County	Alameda	2537	1931	4468	1589	1152	2741
Alameda County	Albany	129	230	359	81	138	219
Alameda County	Berkeley	436	590	1026	283	363	646
Alameda County	Dublin	37	56	93	24	33	57
Alameda County	Emeryville	575	574	1149	307	292	599
Alameda County	Fremont	3737	2526	6263	2491	1523	4014
Alameda County	Hayward	5088	2308	7396	3929	1683	5612
Alameda County	Livermore	1	1	2	1	1	2
Alameda County	Newark	199	194	394	149	129	278
Alameda County	Oakland	12078	9126	21204	10210	7290	17500
Alameda County	Piedmont	25	4	29	14	2	16
Alameda County	Pleasanton	91	135	226	53	70	123
Alameda County	San Leandro	2717	1413	4130	1714	838	2552
Alameda County	Union City	521	236	757	449	184	633
Alameda County	Unincorporated	3018	1687	4705	2110	1126	3236
Alameda County	Total	31189	21011	52200	23404	14824	38228
Contra Costa Co	Antioch	0	2	2	0	1	1
Contra Costa Co	Brentwood	0	0	0	0	0	0
Contra Costa Co	Clayton	0	0	0	0	0	0
Contra Costa Co	Concord	10	9	19	7	6	13
Contra Costa Co	Danville	5	3	8	2	2	4
Contra Costa Co	El Cerrito	17	21	38	10	12	22
Contra Costa Co	Hercules	6	10	16	4	6	10
Contra Costa Co	Lafayette	13	21	33	7	10	17
Contra Costa Co	Martinez	5	6	11	3	3	6
Contra Costa Co	Moraga	6	6	12	3	3	6
Contra Costa Co	Orinda	2	4	6	1	2	3
Contra Costa Co	Pinole	16	14	30	10	8	18
Contra Costa Co	Pittsburg	1	1	1	0	1	1
Contra Costa Co	Pleasant Hill	3	4	7	2	2	4
Contra Costa Co	Richmond	276	397	673	230	307	537
Contra Costa Co	San Pablo	2	2	4	2	2	4
Contra Costa Co	San Ramon	22	28	51	13	14	27
Contra Costa Co	Walnut Creek	5	51	57	3	23	26
Contra Costa Co	Unincorporated	50	53	103	32	31	63
Contra Costa Co	Total	438	632	1070	329	433	762
Marin County	Belvedere	7	7	14	3	3	6
Marin County	Corte Madera	2	4	6	1	2	3
Marin County	Fairfax	1	1	2	1	1	2
Marin County	Larkspur	16	8	24	17	8	25
Marin County	Mill Valley	19	15	34	14	10	24
Marin County	Novato	51	38	89	30	21	51
Marin County	Ross	0	0	0	0	0	0
Marin County	San Anselmo	0	0	1	0	0	0
Marin County	San Rafael	215	312	527	126	166	292
Marin County	Sausalito	62	73	135	39	42	81
Marin County	Tiburon	12	20	33	8	13	21
Marin County	Unincorporated	86	91	176	63	64	127
Marin County	Total	472	568	1040	302	330	632
Napa County	American Canyon	0	0	1	0	0	0
Napa County	Calistoga	0	0	0	0	0	0
Napa County	Napa	3	4	6	2	2	4
Napa County	Saint Helena	0	0	0	0	0	0
Napa County	Yountville	0	0	0	0	0	0
Napa County	Unincorporated	0	0	0	0	0	0
Napa County	Total	4	4	7	2	2	4
San Francisco	San Francisco	3421	8210	11630	2354	5411	7765

TABLE F4 -- SOUTHERN HAYWARD EARTHQUAKE IMPACTS BY CITY (Cont.)

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
San Mateo Co	Atherton	0	0	0	0	0	0
San Mateo Co	Belmont	1	3	4	1	2	3
San Mateo Co	Brisbane	0	0	0	0	0	0
San Mateo Co	Burlingame	6	23	29	3	12	15
San Mateo Co	Colma	0	0	0	0	0	0
San Mateo Co	Daly City	2	15	17	2	12	14
San Mateo Co	East Palo Alto	3	10	13	3	11	14
San Mateo Co	Foster City	4	13	17	2	6	8
San Mateo Co	Half Moon Bay	0	0	0	0	0	0
San Mateo Co	Hillsborough	0	0	0	0	0	0
San Mateo Co	Menlo Park	4	5	9	2	3	5
San Mateo Co	Millbrae	0	1	1	0	0	0
San Mateo Co	Pacifica	0	2	2	0	1	1
San Mateo Co	Portola Valley	0	0	0	0	0	0
San Mateo Co	Redwood City	13	28	41	9	17	26
San Mateo Co	San Bruno	1	2	3	1	1	2
San Mateo Co	San Carlos	1	0	1	0	0	0
San Mateo Co	San Mateo	12	81	93	7	46	53
San Mateo Co	So. San Francisco	2	3	4	1	2	3
San Mateo Co	Woodside	0	0	0	0	0	0
San Mateo Co	Unincorporated	6	3	9	5	2	7
San Mateo Co	Total	54	187	241	36	115	151
Santa Clara Co	Campbell	4	11	14	2	6	8
Santa Clara Co	Cupertino	1	1	1	0	0	0
Santa Clara Co	Gilroy	1	1	1	1	1	2
Santa Clara Co	Los Altos	1	0	1	0	0	0
Santa Clara Co	Los Altos Hills	0	0	0	0	0	0
Santa Clara Co	Los Gatos	1	2	3	0	1	1
Santa Clara Co	Milpitas	592	262	854	465	182	647
Santa Clara Co	Monte Sereno	0	0	0	0	0	0
Santa Clara Co	Morgan Hill	1	1	2	1	0	1
Santa Clara Co	Mountain View	24	72	96	14	40	54
Santa Clara Co	Palo Alto	31	121	153	17	59	76
Santa Clara Co	San Jose	3202	2328	5530	2546	1693	4239
Santa Clara Co	Santa Clara	463	711	1174	297	428	725
Santa Clara Co	Saratoga	1	0	1	0	0	0
Santa Clara Co	Sunnyvale	1574	433	2007	946	243	1189
Santa Clara Co	Unincorporated	91	36	127	65	23	88
Santa Clara Co	Total	5985	3978	9963	4354	2676	7030
Solano County	Benicia	0	0	0	0	0	0
Solano County	Dixon	0	0	0	0	0	0
Solano County	Fairfield	0	1	1	0	1	1
Solano County	Rio Vista	0	0	0	0	0	0
Solano County	Suisun City	2	2	3	1	1	2
Solano County	Vacaville	0	0	0	0	0	0
Solano County	Vallejo	54	68	122	43	50	93
Solano County	Unincorporated	0	0	1	0	0	0
Solano County	Total	56	72	127	44	52	96
Sonoma County	Cloverdale	0	0	0	0	0	0
Sonoma County	Cotati	0	0	0	0	0	0
Sonoma County	Healdsburg	0	0	0	0	0	0
Sonoma County	Petaluma	5	1	7	3	1	4
Sonoma County	Rohnert Park	11	3	13	7	2	9
Sonoma County	Santa Rosa	2	4	5	1	2	3
Sonoma County	Sebastopol	0	0	0	0	0	0
Sonoma County	Sonoma	0	1	1	0	0	0
Sonoma County	Windsor	0	0	0	0	0	0
Sonoma County	Unincorporated	3	1	4	2	0	2
Sonoma County	Total	21	10	30	13	5	18

TABLE F5 -- HAYWARD EARTHQUAKE-- ENTIRE LENGTH EARTHQUAKE IMPACTS BY CITY

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
Alameda County	Alameda	4500	2530	7030	2818	1509	4327
Alameda County	Albany	1017	622	1638	636	372	1008
Alameda County	Berkeley	8885	4488	13372	5768	2762	8530
Alameda County	Dublin	68	113	181	44	66	110
Alameda County	Emeryville	876	606	1482	468	309	777
Alameda County	Fremont	3905	2575	6480	2603	1553	4156
Alameda County	Hayward	5208	2365	7572	4021	1725	5746
Alameda County	Livermore	6	3	9	4	2	6
Alameda County	Newark	206	195	402	154	130	284
Alameda County	Oakland	21459	12369	33828	18141	9880	28021
Alameda County	Piedmont	225	14	239	127	6	133
Alameda County	Pleasanton	192	312	504	113	162	275
Alameda County	San Leandro	2696	1401	4097	1700	831	2531
Alameda County	Union City	820	251	1071	707	195	902
Alameda County	Unincorporated	3012	1647	4659	2099	1096	3195
Alameda County	Total	53074	29489	82563	39403	20598	60001
Contra Costa Co	Antioch	3	5	8	2	3	5
Contra Costa Co	Brentwood	1	0	1	0	0	0
Contra Costa Co	Clayton	0	0	0	0	0	0
Contra Costa Co	Concord	253	157	409	167	96	263
Contra Costa Co	Danville	28	34	63	16	16	32
Contra Costa Co	El Cerrito	546	296	841	320	161	481
Contra Costa Co	Hercules	31	32	63	21	18	39
Contra Costa Co	Lafayette	43	65	108	24	32	56
Contra Costa Co	Martinez	18	24	43	11	13	24
Contra Costa Co	Moraga	18	14	32	10	7	17
Contra Costa Co	Orinda	17	17	33	9	7	16
Contra Costa Co	Pinole	182	69	252	118	40	158
Contra Costa Co	Pittsburg	4	5	9	3	4	7
Contra Costa Co	Pleasant Hill	188	303	491	108	160	268
Contra Costa Co	Richmond	2309	1511	3820	1925	1170	3095
Contra Costa Co	San Pablo	1134	392	1526	1060	347	1407
Contra Costa Co	San Ramon	49	75	125	28	38	66
Contra Costa Co	Walnut Creek	79	175	254	39	79	118
Contra Costa Co	Unincorporated	1033	513	1546	632	305	937
Contra Costa Co	Total	5937	3685	9623	4493	2496	6989
Marin County	Belvedere	24	10	34	10	4	14
Marin County	Corte Madera	9	13	21	5	7	12
Marin County	Fairfax	1	1	2	1	1	2
Marin County	Larkspur	68	28	95	71	26	97
Marin County	Mill Valley	20	15	36	14	10	24
Marin County	Novato	280	152	433	166	85	251
Marin County	Ross	0	0	0	0	0	0
Marin County	San Anselmo	1	0	1	1	0	1
Marin County	San Rafael	539	389	928	315	207	522
Marin County	Sausalito	64	77	141	40	45	85
Marin County	Tiburon	32	26	57	21	17	38
Marin County	Unincorporated	263	117	379	189	82	271
Marin County	Total	1300	828	2128	833	484	1317
Napa County	American Canyon	4	0	5	3	0	3
Napa County	Calistoga	0	0	0	0	0	0
Napa County	Napa	17	10	26	11	6	17
Napa County	Saint Helena	0	0	0	0	0	0
Napa County	Yountville	1	0	1	1	0	1
Napa County	Unincorporated	2	0	2	1	0	1
Napa County	Total	24	10	34	16	6	22
San Francisco	San Francisco	22927	15812	38739	15777	10421	26198

TABLE F5 -- HAYWARD EARTHQUAKE-- ENTIRE LENGTH EARTHQUAKE IMPACTS BY CITY (Cont.)

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
San Mateo Co	Atherton	1	0	1	0	0	0
San Mateo Co	Belmont	1	4	5	1	2	3
San Mateo Co	Brisbane	0	0	0	0	0	0
San Mateo Co	Burlingame	11	50	61	6	26	32
San Mateo Co	Colma	1	0	1	0	0	0
San Mateo Co	Daly City	11	53	63	9	41	50
San Mateo Co	East Palo Alto	41	61	102	44	63	107
San Mateo Co	Foster City	4	13	17	2	6	8
San Mateo Co	Half Moon Bay	0	0	0	0	0	0
San Mateo Co	Hillsborough	0	0	0	0	0	0
San Mateo Co	Menlo Park	27	42	69	16	22	38
San Mateo Co	Millbrae	2	10	12	1	6	7
San Mateo Co	Pacifica	4	7	11	3	4	7
San Mateo Co	Portola Valley	0	0	0	0	0	0
San Mateo Co	Redwood City	325	519	844	217	325	542
San Mateo Co	San Bruno	5	10	15	3	6	9
San Mateo Co	San Carlos	1	0	2	1	0	1
San Mateo Co	San Mateo	21	160	182	13	90	103
San Mateo Co	So. San Francisco	9	15	24	7	11	18
San Mateo Co	Woodside	0	0	0	0	0	0
San Mateo Co	Unincorporated	140	89	229	141	86	227
San Mateo Co	Total	604	1034	1638	464	688	1152
Santa Clara Co	Campbell	8	15	23	5	8	13
Santa Clara Co	Cupertino	4	11	15	2	6	8
Santa Clara Co	Gilroy	1	1	1	1	1	2
Santa Clara Co	Los Altos	2	4	6	1	2	3
Santa Clara Co	Los Altos Hills	0	0	0	0	0	0
Santa Clara Co	Los Gatos	4	4	8	2	2	4
Santa Clara Co	Millpitas	597	262	859	469	182	651
Santa Clara Co	Monte Sereno	0	0	0	0	0	0
Santa Clara Co	Morgan Hill	5	1	6	4	0	4
Santa Clara Co	Mountain View	479	760	1239	281	424	705
Santa Clara Co	Palo Alto	152	326	477	81	159	240
Santa Clara Co	San Jose	3499	2544	6043	2782	1850	4632
Santa Clara Co	Santa Clara	784	1198	1982	503	721	1224
Santa Clara Co	Saratoga	2	0	2	1	0	1
Santa Clara Co	Sunnyvale	1802	790	2592	1083	445	1528
Santa Clara Co	Unincorporated	120	70	190	84	46	130
Santa Clara Co	Total	7458	5985	13443	5299	3846	9145
Solano County	Benicia	1	1	2	1	1	2
Solano County	Dixon	0	0	0	0	0	0
Solano County	Fairfield	3	3	6	3	2	5
Solano County	Rio Vista	0	0	0	0	0	0
Solano County	Suisun City	2	2	4	2	2	4
Solano County	Vacaville	0	1	1	0	0	0
Solano County	Vallejo	619	363	983	492	268	760
Solano County	Unincorporated	18	13	32	13	9	22
Solano County	Total	644	383	1028	511	282	793
Sonoma County	Cloverdale	0	0	0	0	0	0
Sonoma County	Cotati	19	10	28	12	6	18
Sonoma County	Healdsburg	1	1	2	1	1	2
Sonoma County	Petaluma	154	54	208	101	32	133
Sonoma County	Rohnert Park	308	261	569	215	173	388
Sonoma County	Santa Rosa	11	8	19	7	5	12
Sonoma County	Sebastopol	0	1	1	0	0	0
Sonoma County	Sonoma	5	2	7	3	1	4
Sonoma County	Windsor	3	0	4	2	0	2
Sonoma County	Unincorporated	46	8	54	30	6	36
Sonoma County	Total	547	345	892	371	224	595

TABLE F6 -- HEALDSBURG-RODGERS CREEK EARTHQUAKE IMPACTS BY CITY

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
Alameda County	Alameda	465	657	1122	291	392	683
Alameda County	Albany	11	40	50	7	24	31
Alameda County	Berkeley	30	95	125	19	58	77
Alameda County	Dublin	1	1	1	1	0	1
Alameda County	Emeryville	160	280	439	85	142	227
Alameda County	Fremont	3	4	6	2	2	4
Alameda County	Hayward	20	7	26	15	5	20
Alameda County	Livermore	0	1	1	0	0	0
Alameda County	Newark	0	0	0	0	0	0
Alameda County	Oakland	376	940	1317	318	751	1069
Alameda County	Piedmont	1	0	1	1	0	1
Alameda County	Pleasanton	2	2	4	1	1	2
Alameda County	San Leandro	130	27	156	82	16	98
Alameda County	Union City	1	1	1	1	0	1
Alameda County	Unincorporated	2	3	5	1	2	3
Alameda County	Total	1200	2056	3256	824	1393	2217
Contra Costa Co	Antioch	0	2	2	0	1	1
Contra Costa Co	Brentwood	0	0	0	0	0	0
Contra Costa Co	Clayton	0	0	0	0	0	0
Contra Costa Co	Concord	7	8	16	5	5	10
Contra Costa Co	Danville	1	0	1	1	0	1
Contra Costa Co	El Cerrito	3	3	5	1	1	2
Contra Costa Co	Hercules	6	10	16	4	6	10
Contra Costa Co	Lafayette	0	1	1	0	1	1
Contra Costa Co	Martinez	5	6	11	3	3	6
Contra Costa Co	Moraga	0	0	0	0	0	0
Contra Costa Co	Orinda	0	0	0	0	0	0
Contra Costa Co	Pinole	16	14	30	10	8	18
Contra Costa Co	Pittsburg	2	2	4	2	1	3
Contra Costa Co	Pleasant Hill	3	3	6	2	2	4
Contra Costa Co	Richmond	177	245	422	148	190	338
Contra Costa Co	San Pablo	1	2	3	1	2	3
Contra Costa Co	San Ramon	1	1	2	0	0	0
Contra Costa Co	Walnut Creek	2	5	7	1	2	3
Contra Costa Co	Unincorporated	44	49	93	29	28	57
Contra Costa Co	Total	268	350	618	207	250	457
Marin County	Belvedere	7	7	14	3	3	6
Marin County	Corte Madera	2	4	6	1	2	3
Marin County	Fairfax	1	1	2	1	1	2
Marin County	Larkspur	16	9	25	17	8	25
Marin County	Mill Valley	19	15	34	14	10	24
Marin County	Novato	80	73	153	47	41	88
Marin County	Ross	0	0	0	0	0	0
Marin County	San Anselmo	1	0	1	0	0	0
Marin County	San Rafael	216	312	527	126	166	292
Marin County	Sausalito	62	73	135	39	42	81
Marin County	Tiburon	12	20	33	8	13	21
Marin County	Unincorporated	191	101	292	133	69	202
Marin County	Total	607	615	1222	389	355	744
Napa County	American Canyon	4	0	5	3	0	3
Napa County	Calistoga	0	0	0	0	0	0
Napa County	Napa	20	12	32	14	7	21
Napa County	Saint Helena	0	0	0	0	0	0
Napa County	Yountville	3	0	4	2	0	2
Napa County	Unincorporated	6	1	6	3	0	3
Napa County	Total	33	13	46	22	7	29
San Francisco	San Francisco	3241	7860	11101	2230	5181	7411

TABLE F6 – HEALDSBURG-RODGERS CREEK EARTHQUAKE IMPACTS BY CITY (Cont.)

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
San Mateo Co	Atherton	0	0	0	0	0	0
San Mateo Co	Belmont	0	0	0	0	0	0
San Mateo Co	Brisbane	0	0	0	0	0	0
San Mateo Co	Burlingame	3	7	10	2	4	6
San Mateo Co	Colma	0	0	0	0	0	0
San Mateo Co	Daly City	1	3	4	1	2	3
San Mateo Co	East Palo Alto	0	1	1	0	1	1
San Mateo Co	Foster City	0	1	1	0	0	0
San Mateo Co	Half Moon Bay	0	0	0	0	0	0
San Mateo Co	Hillsborough	0	0	0	0	0	0
San Mateo Co	Menlo Park	1	1	2	0	1	1
San Mateo Co	Millbrae	0	1	1	0	0	0
San Mateo Co	Pacifica	0	1	1	0	0	0
San Mateo Co	Portola Valley	0	0	0	0	0	0
San Mateo Co	Redwood City	7	24	31	5	15	20
San Mateo Co	San Bruno	1	1	2	0	1	1
San Mateo Co	San Carlos	0	0	0	0	0	0
San Mateo Co	San Mateo	2	10	12	1	6	7
San Mateo Co	So. San Francisco	1	1	2	0	1	1
San Mateo Co	Woodside	0	0	0	0	0	0
San Mateo Co	Unincorporated	3	2	5	3	2	5
San Mateo Co	Total	19	52	71	12	33	45
Santa Clara Co	Campbell	0	1	1	0	0	0
Santa Clara Co	Cupertino	0	0	0	0	0	0
Santa Clara Co	Gilroy	0	0	0	0	0	0
Santa Clara Co	Los Altos	0	0	0	0	0	0
Santa Clara Co	Los Altos Hills	0	0	0	0	0	0
Santa Clara Co	Los Gatos	0	0	0	0	0	0
Santa Clara Co	Milpitas	2	0	2	1	0	1
Santa Clara Co	Monte Sereno	0	0	0	0	0	0
Santa Clara Co	Morgan Hill	0	0	0	0	0	0
Santa Clara Co	Mountain View	1	5	7	1	3	4
Santa Clara Co	Palo Alto	3	17	19	1	8	9
Santa Clara Co	San Jose	9	21	30	7	15	22
Santa Clara Co	Santa Clara	1	3	4	1	2	3
Santa Clara Co	Saratoga	0	0	0	0	0	0
Santa Clara Co	Sunnyvale	1	4	5	1	2	3
Santa Clara Co	Unincorporated	0	1	1	0	0	0
Santa Clara Co	Total	17	53	70	12	30	42
Solano County	Benicia	0	0	1	0	0	0
Solano County	Dixon	0	0	0	0	0	0
Solano County	Fairfield	2	3	4	1	2	3
Solano County	Rio Vista	0	0	0	0	0	0
Solano County	Suisun City	2	2	3	1	1	2
Solano County	Vacaville	0	1	1	0	0	0
Solano County	Vallejo	57	72	129	45	53	98
Solano County	Unincorporated	0	0	1	0	0	0
Solano County	Total	61	78	139	47	56	103
Sonoma County	Cloverdale	2	1	3	2	1	3
Sonoma County	Cotati	121	66	188	80	41	121
Sonoma County	Healdsburg	61	40	102	43	27	70
Sonoma County	Petaluma	605	158	763	395	96	491
Sonoma County	Rohnert Park	1891	546	2437	1322	361	1683
Sonoma County	Santa Rosa	4022	1823	5844	2609	1119	3728
Sonoma County	Sebastopol	7	7	14	4	4	8
Sonoma County	Sonoma	215	86	301	118	45	163
Sonoma County	Windsor	1099	52	1151	799	34	833
Sonoma County	Unincorporated	2449	419	2868	1639	289	1928
Sonoma County	Total	10472	3197	13669	7011	2017	9028

TABLE F7 – MAACAMA EARTHQUAKE IMPACTS BY CITY

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
Alameda County	Alameda	14	48	62	9	28	37
Alameda County	Albany	0	1	1	0	1	1
Alameda County	Berkeley	3	4	7	2	3	5
Alameda County	Dublin	0	0	0	0	0	0
Alameda County	Emeryville	3	31	34	2	16	18
Alameda County	Fremont	0	1	1	0	1	1
Alameda County	Hayward	0	1	1	0	1	1
Alameda County	Livermore	0	0	0	0	0	0
Alameda County	Newark	0	0	0	0	0	0
Alameda County	Oakland	19	193	213	16	154	170
Alameda County	Piedmont	0	0	0	0	0	0
Alameda County	Pleasanton	0	1	1	0	0	0
Alameda County	San Leandro	3	1	4	2	0	2
Alameda County	Union City	0	0	0	0	0	0
Alameda County	Unincorporated	0	0	0	0	0	0
Alameda County	Total	43	282	325	31	204	235
Contra Costa Co	Antioch	0	2	2	0	1	1
Contra Costa Co	Brentwood	0	0	0	0	0	0
Contra Costa Co	Clayton	0	0	0	0	0	0
Contra Costa Co	Concord	0	1	2	0	1	1
Contra Costa Co	Danville	0	0	0	0	0	0
Contra Costa Co	El Cerrito	0	0	0	0	0	0
Contra Costa Co	Hercules	0	0	0	0	0	0
Contra Costa Co	Lafayette	0	0	0	0	0	0
Contra Costa Co	Martinez	0	0	1	0	0	0
Contra Costa Co	Moraga	0	0	0	0	0	0
Contra Costa Co	Orinda	0	0	0	0	0	0
Contra Costa Co	Pinole	0	0	0	0	0	0
Contra Costa Co	Pittsburg	0	1	1	0	0	0
Contra Costa Co	Pleasant Hill	0	1	1	0	0	0
Contra Costa Co	Richmond	2	4	6	1	3	4
Contra Costa Co	San Pablo	0	0	0	0	0	0
Contra Costa Co	San Ramon	0	0	0	0	0	0
Contra Costa Co	Walnut Creek	0	2	2	0	1	1
Contra Costa Co	Unincorporated	1	2	2	0	0	0
Contra Costa Co	Total	4	13	17	1	6	7
Marin County	Belvedere	0	0	0	0	0	0
Marin County	Corte Madera	0	0	0	0	0	0
Marin County	Fairfax	0	0	0	0	0	0
Marin County	Larkspur	0	1	1	0	0	0
Marin County	Mill Valley	1	1	2	1	0	1
Marin County	Novato	1	1	2	0	0	0
Marin County	Ross	0	0	0	0	0	0
Marin County	San Anselmo	0	0	0	0	0	0
Marin County	San Rafael	3	9	12	1	5	6
Marin County	Sausalito	2	5	7	1	3	4
Marin County	Tiburon	0	0	0	0	0	0
Marin County	Unincorporated	1	2	3	0	2	2
Marin County	Total	8	19	27	3	10	13
Napa County	American Canyon	0	0	0	0	0	0
Napa County	Calistoga	0	0	0	0	0	0
Napa County	Napa	8	7	14	5	4	9
Napa County	Saint Helena	0	0	0	0	0	0
Napa County	Yountville	1	0	1	1	0	1
Napa County	Unincorporated	6	0	7	4	0	4
Napa County	Total	15	7	22	10	4	14
San Francisco	San Francisco	361	1625	1986	248	1071	1319

TABLE F7 – MAACAMA EARTHQUAKE IMPACTS BY CITY (Cont.)

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
San Mateo Co	Atherton	0	0	0	0	0	0
San Mateo Co	Belmont	0	0	0	0	0	0
San Mateo Co	Brisbane	0	0	0	0	0	0
San Mateo Co	Burlingame	1	1	1	0	0	0
San Mateo Co	Colma	0	0	0	0	0	0
San Mateo Co	Daly City	0	1	1	0	0	0
San Mateo Co	East Palo Alto	0	0	0	0	0	0
San Mateo Co	Foster City	0	0	0	0	0	0
San Mateo Co	Half Moon Bay	0	0	0	0	0	0
San Mateo Co	Hillsborough	0	0	0	0	0	0
San Mateo Co	Menlo Park	0	0	0	0	0	0
San Mateo Co	Millbrae	0	0	0	0	0	0
San Mateo Co	Pacifica	0	0	0	0	0	0
San Mateo Co	Portola Valley	0	0	0	0	0	0
San Mateo Co	Redwood City	0	3	3	0	2	2
San Mateo Co	San Bruno	0	1	1	0	0	0
San Mateo Co	San Carlos	0	0	0	0	0	0
San Mateo Co	San Mateo	1	3	4	0	2	2
San Mateo Co	So. San Francisco	0	0	0	0	0	0
San Mateo Co	Woodside	0	0	0	0	0	0
San Mateo Co	Unincorporated	0	0	0	0	0	0
San Mateo Co	Total	2	9	11	0	4	4
Santa Clara Co	Campbell	0	0	0	0	0	0
Santa Clara Co	Cupertino	0	0	0	0	0	0
Santa Clara Co	Gilroy	0	0	0	0	0	0
Santa Clara Co	Los Altos	0	0	0	0	0	0
Santa Clara Co	Los Altos Hills	0	0	0	0	0	0
Santa Clara Co	Los Gatos	0	0	0	0	0	0
Santa Clara Co	Milpitas	0	0	0	0	0	0
Santa Clara Co	Monte Sereno	0	0	0	0	0	0
Santa Clara Co	Morgan Hill	0	0	0	0	0	0
Santa Clara Co	Mountain View	0	1	2	0	1	1
Santa Clara Co	Palo Alto	0	1	1	0	0	0
Santa Clara Co	San Jose	1	4	5	0	3	3
Santa Clara Co	Santa Clara	0	1	1	0	1	1
Santa Clara Co	Saratoga	0	0	0	0	0	0
Santa Clara Co	Sunnyvale	0	1	1	0	1	1
Santa Clara Co	Unincorporated	0	0	0	0	0	0
Santa Clara Co	Total	2	10	11	0	6	6
Solano County	Benicia	0	0	0	0	0	0
Solano County	Dixon	0	0	0	0	0	0
Solano County	Fairfield	1	1	2	0	1	1
Solano County	Rio Vista	0	0	0	0	0	0
Solano County	Suisun City	2	2	3	1	1	2
Solano County	Vacaville	0	1	1	0	0	0
Solano County	Vallejo	2	7	9	2	5	7
Solano County	Unincorporated	0	0	0	0	0	0
Solano County	Total	4	11	15	3	7	10
Sonoma County	Cloverdale	78	36	114	57	25	82
Sonoma County	Cotati	0	0	1	0	0	0
Sonoma County	Healdsburg	67	47	115	48	32	80
Sonoma County	Petaluma	6	1	7	4	1	5
Sonoma County	Rohnert Park	14	3	17	10	2	12
Sonoma County	Santa Rosa	52	44	96	33	27	60
Sonoma County	Sebastopol	0	1	1	0	0	0
Sonoma County	Sonoma	3	2	4	1	1	2
Sonoma County	Windsor	158	15	174	115	10	125
Sonoma County	Unincorporated	250	21	271	166	12	178
Sonoma County	Total	627	170	798	434	110	544

TABLE F8 -- WEST NAPA EARTHQUAKE IMPACTS BY CITY

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
Alameda County	Alameda	45	112	157	28	67	95
Alameda County	Albany	6	20	25	3	12	15
Alameda County	Berkeley	25	85	110	16	52	68
Alameda County	Dublin	1	0	1	0	0	0
Alameda County	Emeryville	6	65	72	3	33	36
Alameda County	Fremont	1	3	5	1	2	3
Alameda County	Hayward	3	4	7	2	3	5
Alameda County	Livermore	0	1	1	0	0	0
Alameda County	Newark	0	0	0	0	0	0
Alameda County	Oakland	209	781	990	177	624	801
Alameda County	Piedmont	1	0	1	0	0	0
Alameda County	Pleasanton	0	1	1	0	0	0
Alameda County	San Leandro	5	5	10	3	3	6
Alameda County	Union City	0	0	0	0	0	0
Alameda County	Unincorporated	1	2	3	0	1	1
Alameda County	Total	302	1080	1382	233	797	1030
Contra Costa Co	Antioch	0	2	2	0	1	1
Contra Costa Co	Brentwood	0	0	0	0	0	0
Contra Costa Co	Clayton	0	0	0	0	0	0
Contra Costa Co	Concord	11	10	22	7	6	13
Contra Costa Co	Danville	1	0	1	0	0	0
Contra Costa Co	El Cerrito	1	1	1	0	0	0
Contra Costa Co	Hercules	6	10	16	4	6	10
Contra Costa Co	Lafayette	0	1	1	0	1	1
Contra Costa Co	Martinez	5	7	12	3	4	7
Contra Costa Co	Moraga	0	0	0	0	0	0
Contra Costa Co	Orinda	0	0	0	0	0	0
Contra Costa Co	Pinole	16	14	30	10	8	18
Contra Costa Co	Pittsburg	1	1	1	0	1	1
Contra Costa Co	Pleasant Hill	3	4	7	2	2	4
Contra Costa Co	Richmond	39	66	106	33	51	84
Contra Costa Co	San Pablo	0	1	1	0	1	1
Contra Costa Co	San Ramon	0	1	1	0	0	0
Contra Costa Co	Walnut Creek	2	6	7	1	2	3
Contra Costa Co	Unincorporated	47	30	77	30	18	48
Contra Costa Co	Total	132	152	284	90	101	191
Marin County	Belvedere	0	0	0	0	0	0
Marin County	Corte Madera	0	0	0	0	0	0
Marin County	Fairfax	0	0	0	0	0	0
Marin County	Larkspur	0	1	1	0	0	0
Marin County	Mill Valley	1	1	2	1	1	2
Marin County	Novato	1	1	2	0	0	0
Marin County	Ross	0	0	0	0	0	0
Marin County	San Anselmo	0	0	0	0	0	0
Marin County	San Rafael	3	9	12	1	5	6
Marin County	Sausalito	2	5	7	1	3	4
Marin County	Tiburon	0	0	0	0	0	0
Marin County	Unincorporated	1	2	3	0	2	2
Marin County	Total	8	19	27	3	11	14
Napa County	American Canyon	565	6	571	388	4	392
Napa County	Calistoga	0	0	0	0	0	0
Napa County	Napa	2367	839	3206	1602	535	2137
Napa County	Saint Helena	0	0	0	0	0	0
Napa County	Yountville	140	16	156	77	8	85
Napa County	Unincorporated	153	43	196	97	25	122
Napa County	Total	3225	904	4129	2164	572	2736
San Francisco	San Francisco	373	1638	2011	256	1080	1336

TABLE F8 -- WEST NAPA EARTHQUAKE IMPACTS BY CITY (Cont.)

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
San Mateo Co	Atherton	0	0	0	0	0	0
San Mateo Co	Belmont	0	0	0	0	0	0
San Mateo Co	Brisbane	0	0	0	0	0	0
San Mateo Co	Burlingame	1	1	2	0	1	1
San Mateo Co	Colma	0	0	0	0	0	0
San Mateo Co	Daly City	0	1	1	0	0	0
San Mateo Co	East Palo Alto	0	1	1	0	1	1
San Mateo Co	Foster City	0	1	1	0	0	0
San Mateo Co	Half Moon Bay	0	0	0	0	0	0
San Mateo Co	Hillsborough	0	0	0	0	0	0
San Mateo Co	Menlo Park	0	0	0	0	0	0
San Mateo Co	Millbrae	0	0	0	0	0	0
San Mateo Co	Pacifica	0	0	0	0	0	0
San Mateo Co	Portola Valley	0	0	0	0	0	0
San Mateo Co	Redwood City	1	3	4	0	2	2
San Mateo Co	San Bruno	0	1	1	0	0	0
San Mateo Co	San Carlos	0	0	0	0	0	0
San Mateo Co	San Mateo	1	4	5	0	2	2
San Mateo Co	So. San Francisco	0	1	1	0	0	0
San Mateo Co	Woodside	0	0	0	0	0	0
San Mateo Co	Unincorporated	0	0	1	0	0	0
San Mateo Co	Total	2	13	15	0	6	6
Santa Clara Co	Campbell	0	0	0	0	0	0
Santa Clara Co	Cupertino	0	0	0	0	0	0
Santa Clara Co	Gilroy	0	0	0	0	0	0
Santa Clara Co	Los Altos	0	0	0	0	0	0
Santa Clara Co	Los Altos Hills	0	0	0	0	0	0
Santa Clara Co	Los Gatos	0	0	0	0	0	0
Santa Clara Co	Milpitas	0	0	0	0	0	0
Santa Clara Co	Monte Sereno	0	0	0	0	0	0
Santa Clara Co	Morgan Hill	0	0	0	0	0	0
Santa Clara Co	Mountain View	1	3	4	0	2	2
Santa Clara Co	Palo Alto	0	1	1	0	0	0
Santa Clara Co	San Jose	4	12	16	3	9	12
Santa Clara Co	Santa Clara	1	3	4	0	2	2
Santa Clara Co	Saratoga	0	0	0	0	0	0
Santa Clara Co	Sunnyvale	0	2	3	0	1	1
Santa Clara Co	Unincorporated	0	0	0	0	0	0
Santa Clara Co	Total	6	23	29	3	14	17
Solano County	Benicia	5	7	12	3	4	7
Solano County	Dixon	0	0	0	0	0	0
Solano County	Fairfield	4	3	7	3	2	5
Solano County	Rio Vista	0	0	0	0	0	0
Solano County	Suisun City	89	94	184	80	77	157
Solano County	Vacaville	0	1	1	0	0	0
Solano County	Vallejo	868	546	1414	689	403	1092
Solano County	Unincorporated	20	13	33	14	9	23
Solano County	Total	986	664	1650	789	495	1284
Sonoma County	Cloverdale	0	0	0	0	0	0
Sonoma County	Cotati	0	0	0	0	0	0
Sonoma County	Healdsburg	0	0	0	0	0	0
Sonoma County	Petaluma	1	1	1	0	0	0
Sonoma County	Rohnert Park	3	2	5	2	1	3
Sonoma County	Santa Rosa	2	4	5	1	2	3
Sonoma County	Sebastopol	0	0	0	0	0	0
Sonoma County	Sonoma	57	23	81	32	12	44
Sonoma County	Windsor	0	0	0	0	0	0
Sonoma County	Unincorporated	27	7	34	18	4	22
Sonoma County	Total	90	36	126	53	19	72

TABLE F9 – CONCORD-GREEN VALLEY EARTHQUAKE IMPACTS BY CITY

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
Alameda County	Alameda	465	657	1122	291	392	683
Alameda County	Albany	6	20	25	4	12	16
Alameda County	Berkeley	26	90	116	17	55	72
Alameda County	Dublin	38	59	97	25	35	60
Alameda County	Emeryville	160	280	439	85	142	227
Alameda County	Fremont	6	7	12	4	4	8
Alameda County	Hayward	27	21	48	21	15	36
Alameda County	Livermore	5	3	8	3	1	4
Alameda County	Newark	1	1	2	1	1	2
Alameda County	Oakland	405	983	1388	343	785	1128
Alameda County	Piedmont	1	0	1	1	0	1
Alameda County	Pleasanton	20	25	45	12	13	25
Alameda County	San Leandro	143	71	214	90	42	132
Alameda County	Union City	1	1	2	1	1	2
Alameda County	Unincorporated	15	11	26	11	8	19
Alameda County	Total	1319	2227	3546	909	1506	2415
Contra Costa Co	Antioch	6	6	13	5	4	9
Contra Costa Co	Brentwood	1	0	1	1	0	1
Contra Costa Co	Clayton	4	0	4	3	0	3
Contra Costa Co	Concord	4192	2273	6465	2765	1396	4161
Contra Costa Co	Danville	32	35	67	17	16	33
Contra Costa Co	El Cerrito	1	1	1	0	0	0
Contra Costa Co	Hercules	7	10	17	5	6	11
Contra Costa Co	Lafayette	26	34	60	14	17	31
Contra Costa Co	Martinez	232	278	510	136	149	285
Contra Costa Co	Moraga	2	2	4	1	1	2
Contra Costa Co	Orinda	1	1	2	1	0	1
Contra Costa Co	Pinole	16	14	30	10	8	18
Contra Costa Co	Pittsburg	94	34	127	79	26	105
Contra Costa Co	Pleasant Hill	704	588	1292	405	311	716
Contra Costa Co	Richmond	50	74	124	41	57	98
Contra Costa Co	San Pablo	0	1	1	0	1	1
Contra Costa Co	San Ramon	49	75	124	28	38	66
Contra Costa Co	Walnut Creek	716	964	1679	354	437	791
Contra Costa Co	Unincorporated	1247	427	1674	758	252	1010
Contra Costa Co	Total	7378	4817	12195	4623	2719	7342
Marin County	Belvedere	0	0	0	0	0	0
Marin County	Corte Madera	0	0	0	0	0	0
Marin County	Fairfax	0	0	0	0	0	0
Marin County	Larkspur	0	1	1	0	0	0
Marin County	Mill Valley	1	1	2	1	1	2
Marin County	Novato	1	1	2	0	0	0
Marin County	Ross	0	0	0	0	0	0
Marin County	San Anselmo	0	0	0	0	0	0
Marin County	San Rafael	3	9	12	1	5	6
Marin County	Sausalito	2	5	7	1	3	4
Marin County	Tiburon	0	0	0	0	0	0
Marin County	Unincorporated	1	2	3	0	2	2
Marin County	Total	8	20	28	3	11	14
Napa County	American Canyon	176	3	180	121	2	123
Napa County	Calistoga	0	0	0	0	0	0
Napa County	Napa	501	356	857	339	227	566
Napa County	Saint Helena	0	0	0	0	0	0
Napa County	Yountville	46	14	60	25	7	32
Napa County	Unincorporated	56	21	77	35	12	47
Napa County	Total	779	395	1173	520	248	768
San Francisco	San Francisco	656	2535	3191	452	1671	2123

TABLE F9 -- CONCORD-GREEN VALLEY EARTHQUAKE IMPACTS BY CITY (Cont.)

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
San Mateo Co	Atherton	0	0	0	0	0	0
San Mateo Co	Belmont	0	0	0	0	0	0
San Mateo Co	Brisbane	0	0	0	0	0	0
San Mateo Co	Burlingame	3	7	10	2	4	6
San Mateo Co	Colma	0	0	0	0	0	0
San Mateo Co	Daly City	1	3	4	1	2	3
San Mateo Co	East Palo Alto	1	2	3	1	2	3
San Mateo Co	Foster City	0	1	1	0	0	0
San Mateo Co	Half Moon Bay	0	0	0	0	0	0
San Mateo Co	Hillsborough	0	0	0	0	0	0
San Mateo Co	Menlo Park	1	2	3	1	1	2
San Mateo Co	Millbrae	0	1	1	0	0	0
San Mateo Co	Pacifica	0	1	1	0	0	0
San Mateo Co	Portola Valley	0	0	0	0	0	0
San Mateo Co	Redwood City	7	24	31	5	15	20
San Mateo Co	San Bruno	1	1	2	0	1	1
San Mateo Co	San Carlos	0	0	0	0	0	0
San Mateo Co	San Mateo	2	10	12	1	6	7
San Mateo Co	So. San Francisco	1	1	2	0	1	1
San Mateo Co	Woodside	0	0	0	0	0	0
San Mateo Co	Unincorporated	3	2	5	3	2	5
San Mateo Co	Total	20	54	74	14	34	48
Santa Clara Co	Campbell	1	1	2	0	1	1
Santa Clara Co	Cupertino	0	1	1	0	0	0
Santa Clara Co	Gilroy	0	0	1	0	0	0
Santa Clara Co	Los Altos	0	0	0	0	0	0
Santa Clara Co	Los Altos Hills	0	0	0	0	0	0
Santa Clara Co	Los Gatos	0	1	1	0	0	0
Santa Clara Co	Milpitas	3	2	5	3	1	4
Santa Clara Co	Monte Sereno	0	0	0	0	0	0
Santa Clara Co	Morgan Hill	0	0	0	0	0	0
Santa Clara Co	Mountain View	9	26	35	5	15	20
Santa Clara Co	Palo Alto	6	25	31	3	12	15
Santa Clara Co	San Jose	67	93	160	54	68	122
Santa Clara Co	Santa Clara	12	21	34	8	13	21
Santa Clara Co	Saratoga	0	0	0	0	0	0
Santa Clara Co	Sunnyvale	35	14	49	21	8	29
Santa Clara Co	Unincorporated	3	2	5	2	2	4
Santa Clara Co	Total	136	188	324	96	120	216
Solano County	Benicia	224	176	400	140	100	240
Solano County	Dixon	0	0	0	0	0	0
Solano County	Fairfield	290	247	537	228	183	411
Solano County	Rio Vista	0	0	0	0	0	0
Solano County	Suisun City	262	167	429	235	137	372
Solano County	Vacaville	8	3	10	6	2	8
Solano County	Vallejo	826	562	1389	656	415	1071
Solano County	Unincorporated	82	17	99	59	11	70
Solano County	Total	1692	1173	2865	1324	848	2172
Sonoma County	Cloverdale	0	0	0	0	0	0
Sonoma County	Cotati	0	0	0	0	0	0
Sonoma County	Healdsburg	0	0	0	0	0	0
Sonoma County	Petaluma	3	1	4	2	0	2
Sonoma County	Rohnert Park	11	3	13	7	2	9
Sonoma County	Santa Rosa	2	4	5	1	2	3
Sonoma County	Sebastopol	0	0	0	0	0	0
Sonoma County	Sonoma	3	2	4	2	1	3
Sonoma County	Windsor	0	0	0	0	0	0
Sonoma County	Unincorporated	5	2	8	4	1	5
Sonoma County	Total	24	11	35	16	6	22

TABLE F10 -- NORTHERN CALAVERAS EARTHQUAKE IMPACTS BY CITY

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
Alameda County	Alameda	465	657	1122	291	392	683
Alameda County	Albany	6	20	25	3	12	15
Alameda County	Berkeley	25	85	110	16	53	69
Alameda County	Dublin	289	191	480	188	112	300
Alameda County	Emeryville	160	280	439	85	142	227
Alameda County	Fremont	149	211	360	100	127	227
Alameda County	Hayward	247	267	513	190	195	385
Alameda County	Livermore	26	28	54	17	16	33
Alameda County	Newark	37	58	96	28	39	67
Alameda County	Oakland	400	955	1355	338	763	1101
Alameda County	Piedmont	1	0	1	1	0	1
Alameda County	Pleasanton	733	524	1257	431	273	704
Alameda County	San Leandro	144	72	216	91	43	134
Alameda County	Union City	26	33	58	22	25	47
Alameda County	Unincorporated	107	37	144	79	23	102
Alameda County	Total	2813	3418	6231	1880	2215	4095
Contra Costa Co	Antioch	3	5	8	2	3	5
Contra Costa Co	Brentwood	1	0	1	0	0	0
Contra Costa Co	Clayton	0	0	0	0	0	0
Contra Costa Co	Concord	327	244	571	216	150	366
Contra Costa Co	Danville	96	55	151	53	25	78
Contra Costa Co	El Cerrito	1	1	1	0	0	0
Contra Costa Co	Hercules	6	10	16	4	6	10
Contra Costa Co	Lafayette	19	26	45	11	13	24
Contra Costa Co	Martinez	10	14	24	6	7	13
Contra Costa Co	Moraga	4	3	8	2	2	4
Contra Costa Co	Orinda	0	0	0	0	0	0
Contra Costa Co	Pinole	16	14	30	10	8	18
Contra Costa Co	Pittsburg	4	5	9	3	4	7
Contra Costa Co	Pleasant Hill	197	315	512	113	167	280
Contra Costa Co	Richmond	37	63	100	31	48	79
Contra Costa Co	San Pablo	0	1	1	0	1	1
Contra Costa Co	San Ramon	474	449	922	272	226	498
Contra Costa Co	Walnut Creek	413	692	1105	204	314	518
Contra Costa Co	Unincorporated	411	202	612	244	116	360
Contra Costa Co	Total	2017	2097	4114	1171	1090	2261
Marin County	Belvedere	0	0	0	0	0	0
Marin County	Corte Madera	0	0	0	0	0	0
Marin County	Fairfax	0	0	0	0	0	0
Marin County	Larkspur	0	1	1	0	0	0
Marin County	Mill Valley	1	1	2	1	1	2
Marin County	Novato	1	1	1	0	0	0
Marin County	Ross	0	0	0	0	0	0
Marin County	San Anselmo	0	0	0	0	0	0
Marin County	San Rafael	3	9	12	1	5	6
Marin County	Sausalito	2	5	7	1	3	4
Marin County	Tiburon	0	0	0	0	0	0
Marin County	Unincorporated	1	2	3	0	2	2
Marin County	Total	8	19	27	3	11	14
Napa County	American Canyon	0	0	1	0	0	0
Napa County	Calistoga	0	0	0	0	0	0
Napa County	Napa	8	6	14	5	4	9
Napa County	Saint Helena	0	0	0	0	0	0
Napa County	Yountville	0	0	0	0	0	0
Napa County	Unincorporated	1	0	1	0	0	0
Napa County	Total	8	7	15	5	4	9
San Francisco	San Francisco	486	1868	2354	334	1231	1565

TABLE F10 -- NORTHERN CALAVERAS EARTHQUAKE IMPACTS BY CITY (Cont.)

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
San Mateo Co	Atherton	0	0	0	0	0	0
San Mateo Co	Belmont	0	0	0	0	0	0
San Mateo Co	Brisbane	0	0	0	0	0	0
San Mateo Co	Burlingame	1	1	2	0	1	1
San Mateo Co	Colma	0	0	0	0	0	0
San Mateo Co	Daly City	1	2	2	1	1	2
San Mateo Co	East Palo Alto	1	2	3	1	2	3
San Mateo Co	Foster City	0	1	1	0	0	0
San Mateo Co	Half Moon Bay	0	0	0	0	0	0
San Mateo Co	Hillsborough	0	0	0	0	0	0
San Mateo Co	Menlo Park	1	2	3	1	1	2
San Mateo Co	Millbrae	0	0	0	0	0	0
San Mateo Co	Pacifica	0	0	0	0	0	0
San Mateo Co	Portola Valley	0	0	0	0	0	0
San Mateo Co	Redwood City	7	24	31	5	15	20
San Mateo Co	San Bruno	1	1	2	0	1	1
San Mateo Co	San Carlos	0	0	0	0	0	0
San Mateo Co	San Mateo	1	5	6	1	3	4
San Mateo Co	So. San Francisco	1	1	2	0	1	1
San Mateo Co	Woodside	0	0	0	0	0	0
San Mateo Co	Unincorporated	3	2	5	3	2	5
San Mateo Co	Total	16	42	58	12	27	39
Santa Clara Co	Campbell	2	3	4	1	1	2
Santa Clara Co	Cupertino	0	1	1	0	0	0
Santa Clara Co	Gilroy	1	1	1	1	1	2
Santa Clara Co	Los Altos	0	0	0	0	0	0
Santa Clara Co	Los Altos Hills	0	0	0	0	0	0
Santa Clara Co	Los Gatos	0	1	2	0	1	1
Santa Clara Co	Milpitas	162	139	301	127	96	223
Santa Clara Co	Monte Sereno	0	0	0	0	0	0
Santa Clara Co	Morgan Hill	1	1	2	1	0	1
Santa Clara Co	Mountain View	9	26	35	5	15	20
Santa Clara Co	Palo Alto	6	25	31	3	12	15
Santa Clara Co	San Jose	1117	894	2011	889	650	1539
Santa Clara Co	Santa Clara	12	21	34	8	13	21
Santa Clara Co	Saratoga	0	0	0	0	0	0
Santa Clara Co	Sunnyvale	35	14	49	21	8	29
Santa Clara Co	Unincorporated	14	5	19	10	3	13
Santa Clara Co	Total	1359	1131	2490	1066	800	1866
Solano County	Benicia	0	0	1	0	0	0
Solano County	Dixon	0	0	0	0	0	0
Solano County	Fairfield	3	3	6	3	2	5
Solano County	Rio Vista	0	0	0	0	0	0
Solano County	Suisun City	2	2	4	2	2	4
Solano County	Vacaville	0	1	1	0	0	0
Solano County	Vallejo	54	68	122	43	50	93
Solano County	Unincorporated	0	0	1	0	0	0
Solano County	Total	60	74	134	48	54	102
Sonoma County	Cloverdale	0	0	0	0	0	0
Sonoma County	Cotati	0	0	0	0	0	0
Sonoma County	Healdsburg	0	0	0	0	0	0
Sonoma County	Petaluma	1	0	1	0	0	0
Sonoma County	Rohnert Park	0	1	1	0	0	0
Sonoma County	Santa Rosa	0	1	1	0	0	0
Sonoma County	Sebastopol	0	0	0	0	0	0
Sonoma County	Sonoma	0	1	1	0	0	0
Sonoma County	Windsor	0	0	0	0	0	0
Sonoma County	Unincorporated	1	1	1	0	0	0
Sonoma County	Total	2	3	5	0	0	0

TABLE F11 -- GREENVILLE EARTHQUAKE IMPACTS BY CITY

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
Alameda County	Alameda	45	112	157	28	67	95
Alameda County	Albany	1	2	3	1	1	2
Alameda County	Berkeley	15	54	69	10	33	43
Alameda County	Dublin	18	25	43	12	15	27
Alameda County	Emeryville	4	44	48	2	22	24
Alameda County	Fremont	3	4	7	2	2	4
Alameda County	Hayward	18	7	24	14	5	19
Alameda County	Livermore	388	322	710	248	186	434
Alameda County	Newark	1	1	1	0	0	0
Alameda County	Oakland	203	773	977	172	618	790
Alameda County	Piedmont	1	0	1	0	0	0
Alameda County	Pleasanton	114	189	304	67	99	166
Alameda County	San Leandro	5	8	13	3	5	8
Alameda County	Union City	0	0	0	0	0	0
Alameda County	Unincorporated	54	3	57	41	1	42
Alameda County	Total	870	1543	2413	600	1054	1654
Contra Costa Co	Antioch	100	0	100	75	72	147
Contra Costa Co	Brentwood	31	0	31	25	3	28
Contra Costa Co	Clayton	4	4	9	3	0	3
Contra Costa Co	Concord	217	0	217	143	85	228
Contra Costa Co	Danville	7	4	11	4	1	5
Contra Costa Co	El Cerrito	0	0	0	0	0	0
Contra Costa Co	Hercules	0	0	0	0	0	0
Contra Costa Co	Lafayette	0	0	0	0	1	1
Contra Costa Co	Martinez	9	1	10	5	7	12
Contra Costa Co	Moraga	0	14	14	0	0	0
Contra Costa Co	Orinda	0	0	0	0	0	0
Contra Costa Co	Pinole	1	14	14	0	0	0
Contra Costa Co	Pittsburg	169	1	170	142	89	231
Contra Costa Co	Pleasant Hill	70	114	185	40	66	106
Contra Costa Co	Richmond	5	124	129	4	7	11
Contra Costa Co	San Pablo	0	2	2	0	0	0
Contra Costa Co	San Ramon	4	0	4	2	1	3
Contra Costa Co	Walnut Creek	7	1	8	3	24	27
Contra Costa Co	Unincorporated	485	347	832	305	38	343
Contra Costa Co	Total	1108	626	1734	751	394	1145
Marin County	Belvedere	0	0	0	0	0	0
Marin County	Corte Madera	0	0	0	0	0	0
Marin County	Fairfax	0	0	0	0	0	0
Marin County	Larkspur	0	0	0	0	0	0
Marin County	Mill Valley	1	0	1	1	1	2
Marin County	Novato	1	1	2	0	0	0
Marin County	Ross	0	0	0	0	0	0
Marin County	San Anselmo	0	0	0	0	0	0
Marin County	San Rafael	3	0	3	1	5	6
Marin County	Sausalito	2	0	2	1	3	4
Marin County	Tiburon	0	0	0	0	0	0
Marin County	Unincorporated	1	18	19	0	2	2
Marin County	Total	8	19	27	3	11	14
Napa County	American Canyon	0	1	1	0	0	0
Napa County	Calistoga	0	0	0	0	0	0
Napa County	Napa	8	0	8	5	4	9
Napa County	Saint Helena	0	6	6	0	0	0
Napa County	Yountville	0	0	0	0	0	0
Napa County	Unincorporated	1	0	0	0	0	0
Napa County	Total	8	6	14	5	4	9
San Francisco	San Francisco	370	206	576	254	136	390

TABLE F11 – GREENVILLE EARTHQUAKE IMPACTS BY CITY (Cont.)

County	City	Red Tagged Units	Multi-Family Yellow Tagged Units	Total Uninhabitable Units	Shelter Population from Red Tagged Units	Shelter Population from Yellow Tagged Units	Total Shelter Population
San Mateo Co	Atherton	0	0	0	0	0	0
San Mateo Co	Belmont	0	0	0	0	0	0
San Mateo Co	Brisbane	0	0	0	0	0	0
San Mateo Co	Burlingame	1	0	1	0	1	1
San Mateo Co	Colma	0	1	1	0	0	0
San Mateo Co	Daly City	0	0	0	0	0	0
San Mateo Co	East Palo Alto	0	1	1	0	1	1
San Mateo Co	Foster City	0	0	0	0	0	0
San Mateo Co	Half Moon Bay	0	1	1	0	0	0
San Mateo Co	Hillsborough	0	0	0	0	0	0
San Mateo Co	Menlo Park	0	0	0	0	0	0
San Mateo Co	Millbrae	0	1	1	0	0	0
San Mateo Co	Pacifica	0	0	0	0	0	0
San Mateo Co	Portola Valley	0	0	0	0	0	0
San Mateo Co	Redwood City	1	0	1	0	2	2
San Mateo Co	San Bruno	0	3	3	0	0	0
San Mateo Co	San Carlos	0	1	1	0	0	0
San Mateo Co	San Mateo	1	0	1	0	2	2
San Mateo Co	So. San Francisco	0	4	4	0	0	0
San Mateo Co	Woodside	0	0	0	0	0	0
San Mateo Co	Unincorporated	0	1	2	0	0	0
San Mateo Co	Total	3	13	16	0	6	6
Santa Clara Co	Campbell	0	0	0	0	1	1
Santa Clara Co	Cupertino	0	1	1	0	0	0
Santa Clara Co	Gilroy	1	0	1	1	1	2
Santa Clara Co	Los Altos	0	0	0	0	0	0
Santa Clara Co	Los Altos Hills	0	0	0	0	0	0
Santa Clara Co	Los Gatos	0	0	0	0	0	0
Santa Clara Co	Milpitas	3	0	3	2	1	3
Santa Clara Co	Monte Sereno	0	1	1	0	0	0
Santa Clara Co	Morgan Hill	0	0	0	0	0	0
Santa Clara Co	Mountain View	1	0	1	1	2	3
Santa Clara Co	Palo Alto	2	4	6	1	7	8
Santa Clara Co	San Jose	36	0	36	29	28	57
Santa Clara Co	Santa Clara	3	0	3	2	4	6
Santa Clara Co	Saratoga	0	6	6	0	0	0
Santa Clara Co	Sunnyvale	2	0	2	1	2	3
Santa Clara Co	Unincorporated	1	59	60	0	0	0
Santa Clara Co	Total	48	72	120	37	46	83
Solano County	Benicia	0	0	0	0	0	0
Solano County	Dixon	0	0	1	0	0	0
Solano County	Fairfield	4	0	4	3	2	5
Solano County	Rio Vista	1	3	5	1	1	2
Solano County	Suisun City	90	1	90	80	77	157
Solano County	Vacaville	3	94	97	2	1	3
Solano County	Vallejo	54	1	55	43	50	93
Solano County	Unincorporated	3	69	72	2	0	2
Solano County	Total	155	169	324	131	131	262
Sonoma County	Cloverdale	0	0	0	0	0	0
Sonoma County	Cotati	0	0	0	0	0	0
Sonoma County	Healdsburg	0	0	0	0	0	0
Sonoma County	Petaluma	1	0	1	0	0	0
Sonoma County	Rohnert Park	0	0	1	0	0	0
Sonoma County	Santa Rosa	0	0	0	0	1	1
Sonoma County	Sebastopol	0	1	1	0	0	0
Sonoma County	Sonoma	0	0	0	0	0	0
Sonoma County	Windsor	0	0	0	0	0	0
Sonoma County	Unincorporated	1	2	2	0	0	0
Sonoma County	Total	2	3	5	0	1	1

96 00444

U.C. BERKELEY LIBRARIES



C123315495

INSTITUTE OF GOVERNMENTAL
STUDIES LIBRARY

FEB 14 2025

UNIVERSITY OF CALIFORNIA



ASSOCIATION
OF BAY AREA
GOVERNMENTS

MetroCenter
Eighth & Oak Streets
Oakland
(510) 464-7900

Mailing Address:
P.O. Box 2050
Oakland, CA 94604-2050

**EARTHQUAKE
PREPAREDNESS
PROGRAM**

